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GENERAL ELECTRIC REVIEW

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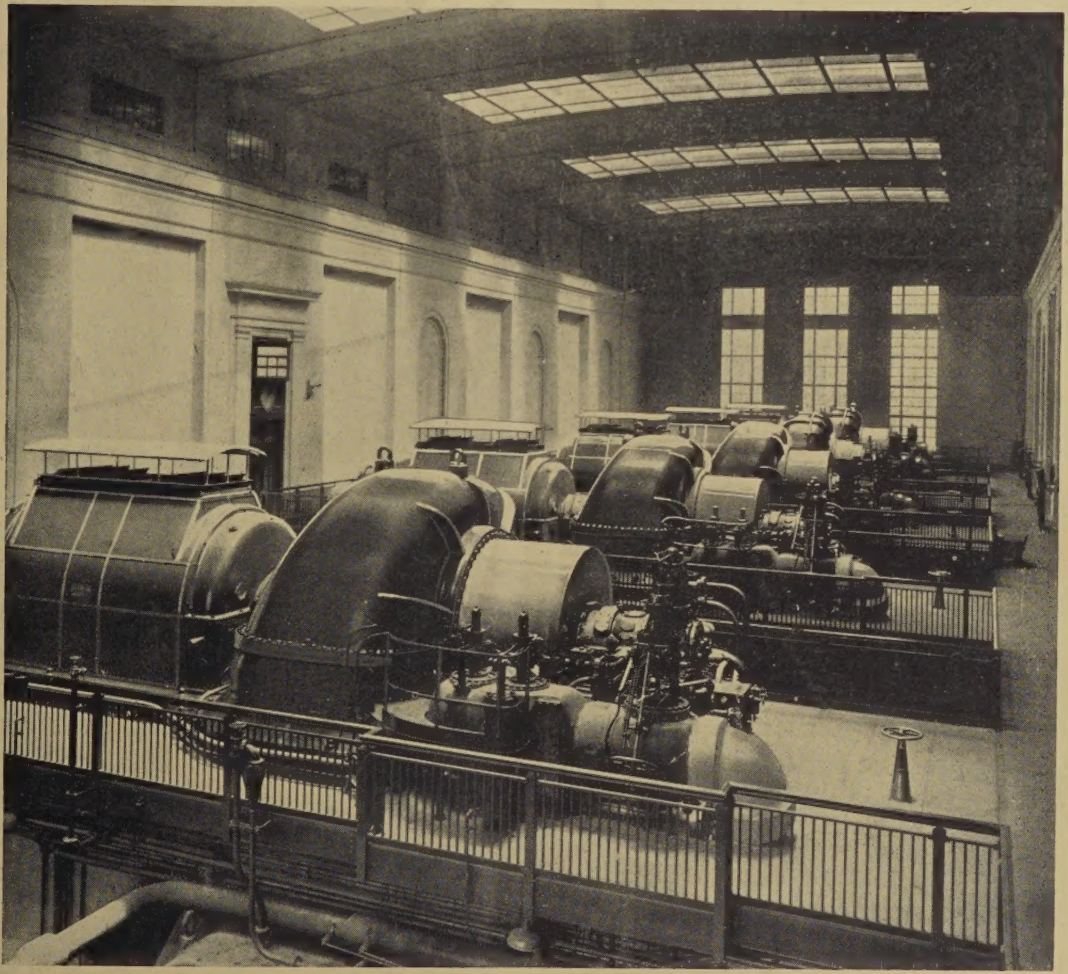
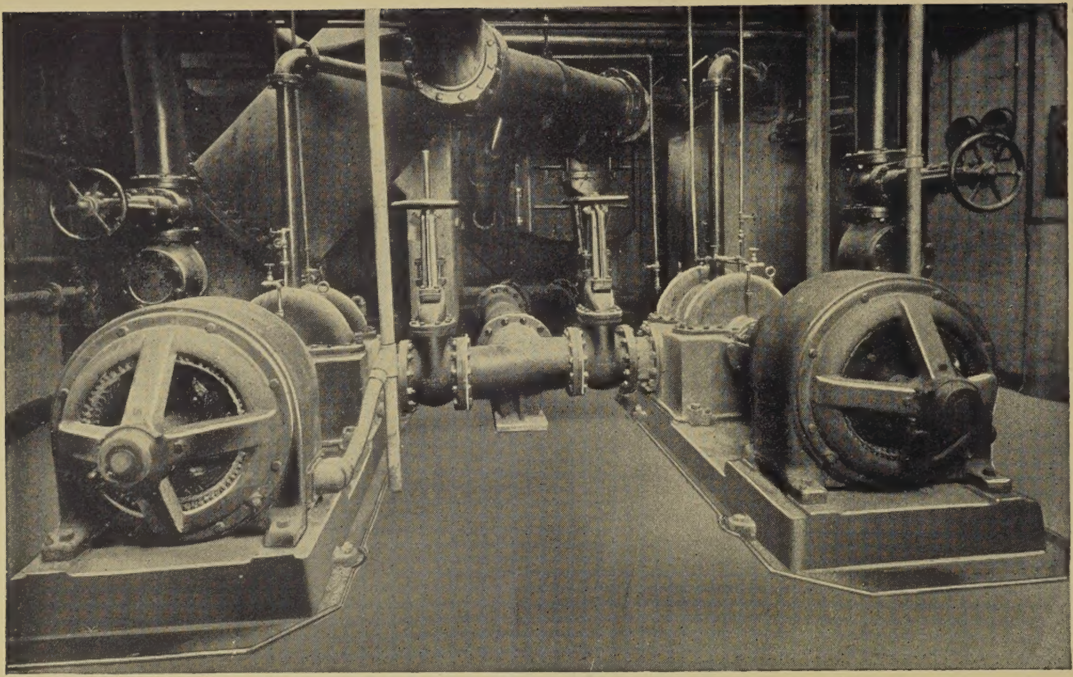


WHERE BUT FEW B.T.U.'S ARE REQUIRED TO PRODUCE A KW-HR.
Large turbine generators in the Delaware Station operated in parallel to supply the bulk of Philadelphia's electric service. This practice of combining the output of two or more alternating-current generators requires convenient and reliable synchronizing equipment that takes several factors into account. This is not the case with the installation pictured in our frontispiece. A detailed analysis of the fundamentals of synchronizing is begun by Mr. Auchincloss in this issue

In This Issue:

Light and Our Eyes
Inverter
More About the Atom
Flywheel Design
Crystal Structure
Synchronizing
South Africa Electrifies
Miniature Lamps in R.R. Signaling
Starters for Synchronous Motors



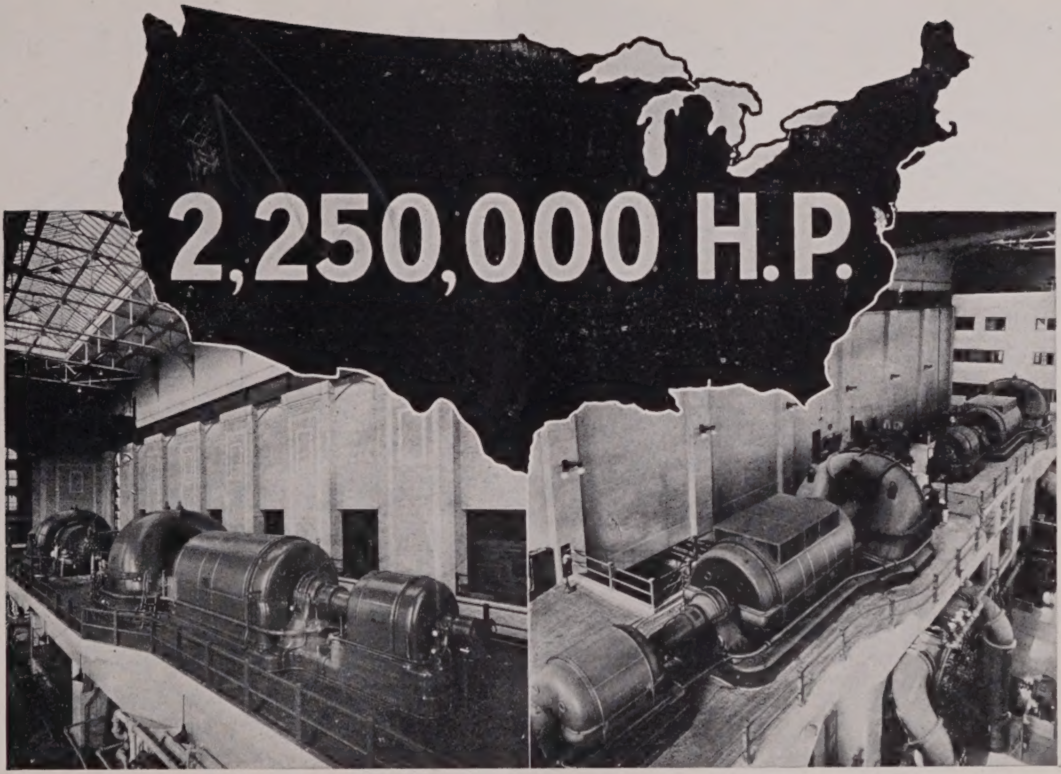
Eliminate Corrosion

Corrosion in piping and economizers is due to dissolved air

A PROPERLY designed surface condenser will automatically produce air free condensate—A Wheeler pressure-sealed Hotwell pump will keep it air free.

The above photograph shows duplicate Wheeler, two-stage, pressure-sealed hotwell pumps in the New Twin Branch Station of the American Gas and Electric Co. The impellers in these pumps are so placed that the stuffing boxes are under pressure from the discharge of the pump. It is impossible for air to gain access to the condensate through the stuffing boxes of the pump. This eliminates the one point in the system where air tends to leak into a good closed feed water system, at all other points the pressure of the condensate being greater than the atmospheric pressure.

WHEELER CONDENSER & ENGINEERING CO.
149 Broadway, New York
Works - CARTERET, N.J., NEWBURGH, N.Y.



Turbine Rooms of Super Power Stations Recently Completed in Boston and Los Angeles

LOW construction costs and high economy are characteristic of Stone & Webster power stations. This is one result of an experience covering the whole era of steam station development. With the completion of the stations shown above, Stone & Webster power construction work exceeds 2,250,000 horse power.

STONE & WEBSTER

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DESIGN · BUILD
OPERATE
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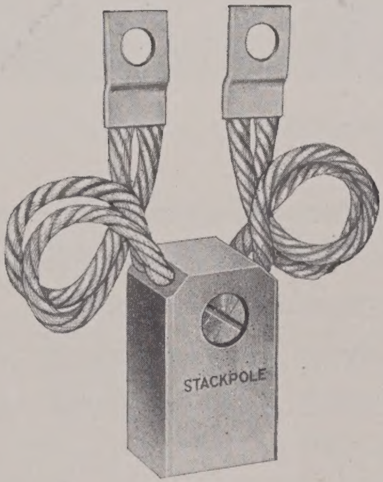
BOSTON, 147 Milk Street
CHICAGO, First National Bank Bldg.
SAN FRANCISCO, Holbrook Bldg.

NEW YORK, 120 Broadway
PHILADELPHIA, Real Estate Trust Bldg.
PITTSBURGH, Union Trust Bldg.

Robb Beebe
There's no law against it –



STACKPOLE
CARBON COMPANY
St. Mary's, Penna.

but there should be one prohibiting the use of inferior Carbon Brushes.

Poor Carbon Brushes always cause pitting, chattering, sparking, heating, etc., that result in machine troubles and failures, and excessive brush maintenance.

With STACKPOLES on the job—you are always assured of cool operation and perfect commutation with minimum brush and commutator wear.

If you're interested in eliminating your Carbon Brush problems—let Stackpole Engineers co-operate with you.

Stackpole
carbon brushes

The answer to most straining problems

Install Twin Strainers

Many Twin Strainers are installed in the suction lines of individual pumps. Their adaptability to space limitations is remarkable. They may be set in the line where most convenient. They may be installed in any position. They require no foundations.

Thus installed, they constantly stand guard—an unfailing protection to the pump against clogging, damage and shutdown.

The service of a Twin Strainer is not interrupted in the process of cleaning. One of the twin chambers is always in service, while the other is cut out and may be opened up and the basket cleaned.

ELLIOTT COMPANY

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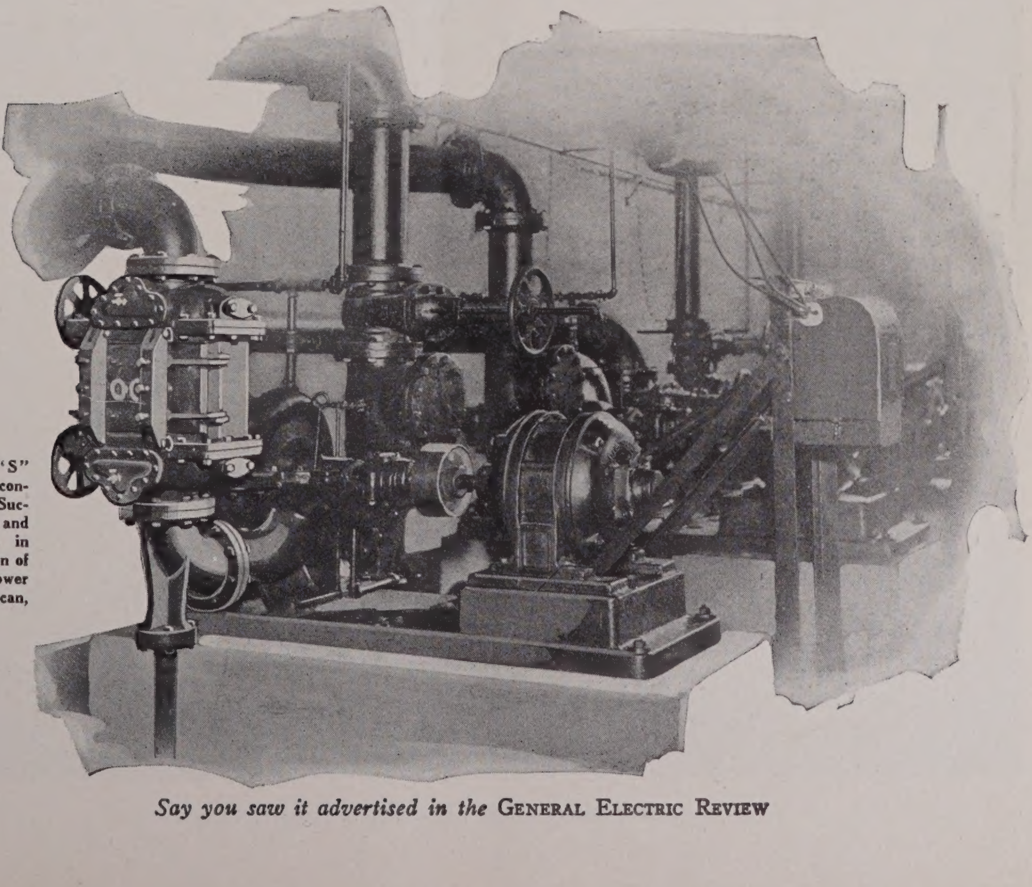
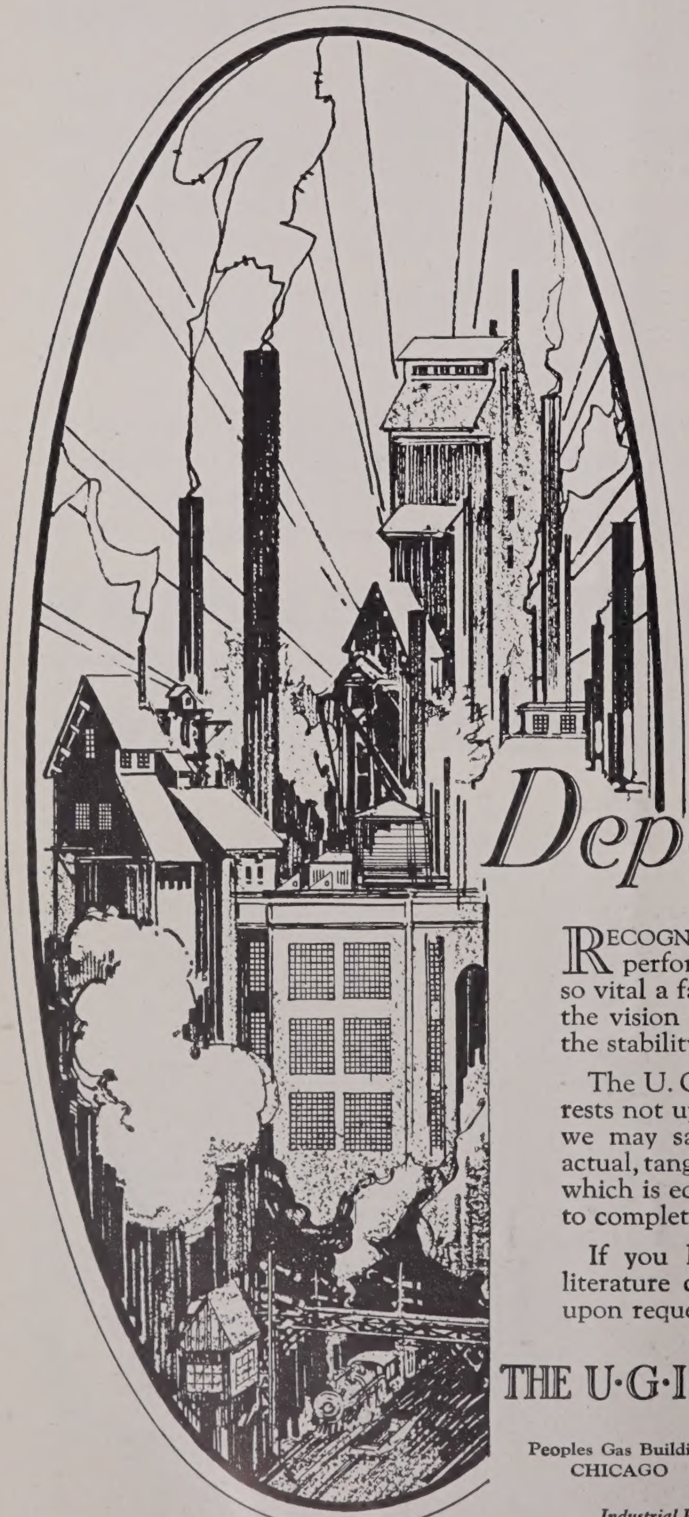


6-inch Type "S" Twin Strainer connected in Pump Suction of Auxiliary and Service Pump, in the Tiger Station of the Southern Power Company, Duncan, S. C.



Dependability—

RECOGNITION must be based upon results, for performance is the measure of ability. Even so vital a factor as experience means little without the vision to plan, the competence to build and the stability to finance.

The U. G. I. Contracting Company's recognition rests not upon what others may say of us or what we may say of ourselves, but rather upon the actual, tangible accomplishments of an organization which is equipped both practically and financially to complete any obligation it assumes.

If you have a building problem, interesting literature concerning our activities will be sent upon request.

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Philadelphia, U. S. A.

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CHICAGO

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BUILDERS OF

Industrial Plants ***Steam Power Plants*** ***Hydro Developments***
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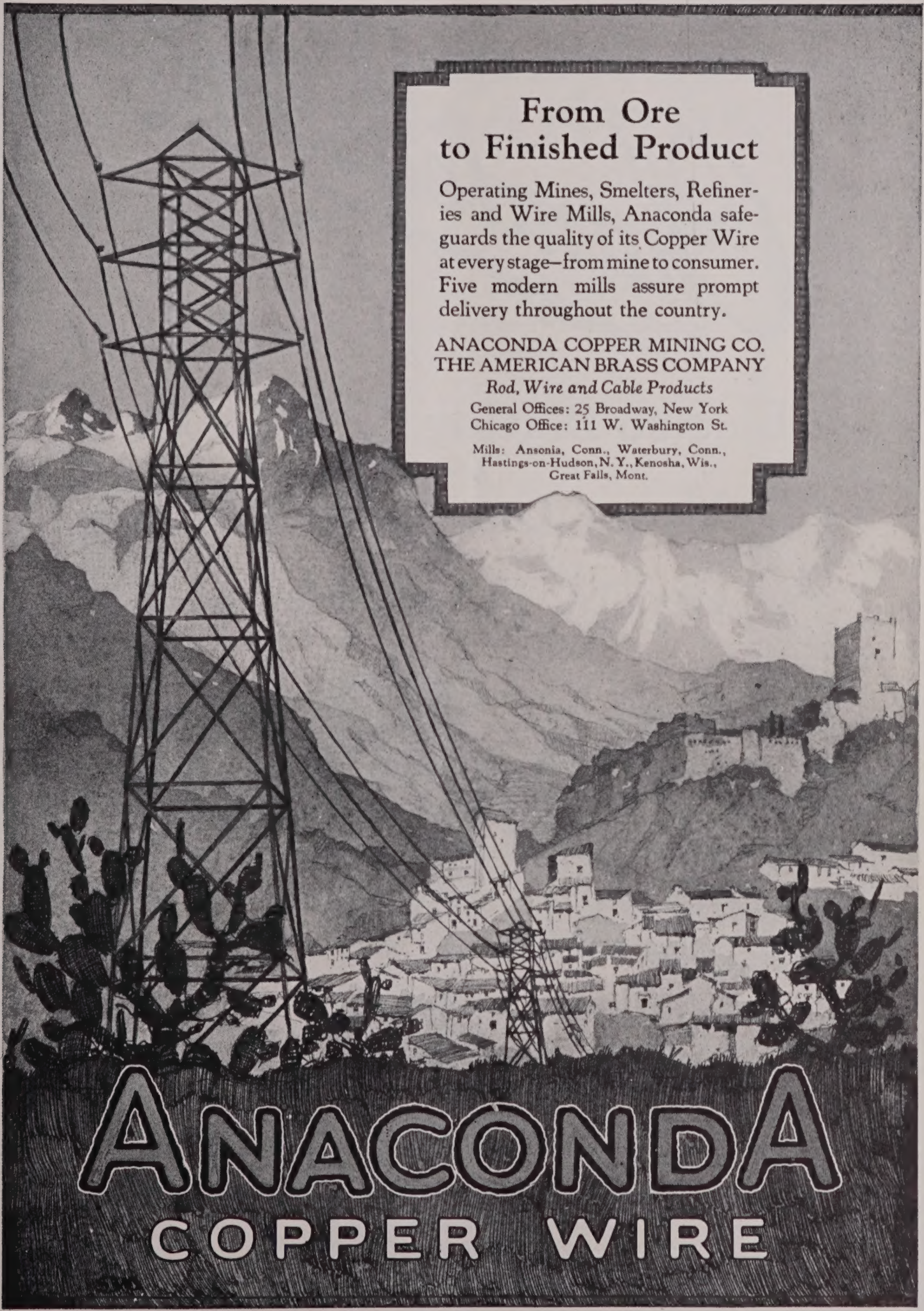


From Ore to Finished Product

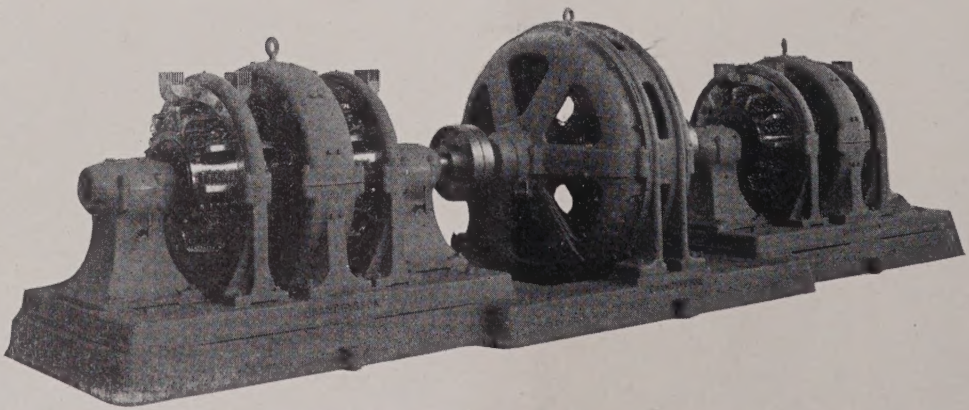
Operating Mines, Smelters, Refineries and Wire Mills, Anaconda safeguards the quality of its Copper Wire at every stage—from mine to consumer. Five modern mills assure prompt delivery throughout the country.

ANACONDA COPPER MINING CO.
THE AMERICAN BRASS COMPANY
Rod, Wire and Cable Products
General Offices: 25 Broadway, New York
Chicago Office: 111 W. Washington St.

Mills: Ansonia, Conn., Waterbury, Conn., Hastings-on-Hudson, N. Y., Kenosha, Wis., Great Falls, Mont.

Chandeysson

Electro Plating Generators
and
Motor Generator Sets
with
General Electric Motors



GENERATOR, 15,000 AMP., 8 VOLTS, 360 R.P.M.
GENERAL ELECTRIC MOTOR, 200 H.P., 3-PHASE, 60 CYCLES, 2300 VOLTS

Types T-B-P
25 to 15,000 Amperes

CHANDEYSSON ELECTRIC COMPANY

4092 Bingham Ave. St. Louis, Mo.

New Departure Ball Bearings

BALL BEARINGS—
the Latest Achievements in Motor Economy

NEW DEPARTURES are as long lived as the motors themselves. They can be housed to permanently prevent the leakage of lubricant or entrance of abrasive foreign material.

From these two basic superiorities follow many additional advantages:

The motor has a longer life because the rotor cannot rub on the stator.

The motor shaft and rotor are always in correct position, maintaining highest efficiency and power-factor.

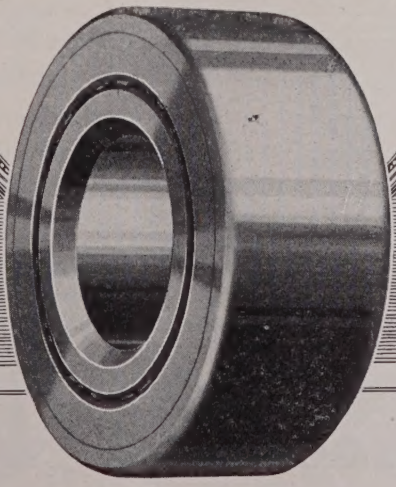
The lubricant stays in the bearing closure, keeping insulation free of oil, giving exceptionally long life to the windings.

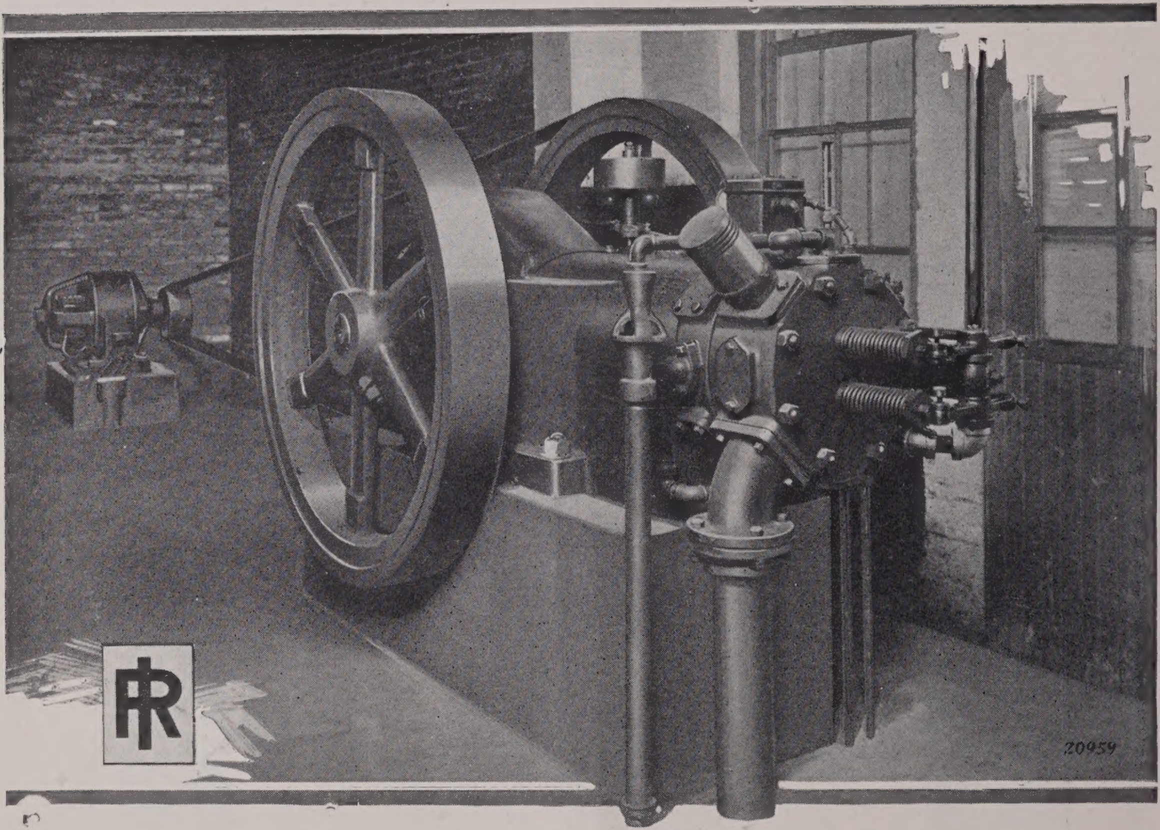
The motor has a lower maintenance cost. Important economies are effected in upkeep expense because lubricant need be supplied only at infrequent intervals. The motor seldom needs cleaning. Rewinding expenses are practically eliminated.

The surface of the motor is free from oil which would damage material in process.

New Departure Ball Bearings permit a very compact motor design because of minimum space occupied along the shaft.

THE NEW DEPARTURE MANUFACTURING COMPANY
Detroit *Bristol, Conn.* Chicago





I-R Direct Injection Oil Engines

50—100—150 B.H.P. SIZES

The Ingersoll-Rand Type "PO" is a small oil engine operating with full Diesel economy at any load. It burns any fuel oil that can be used in any other Diesel engine. It burns all of the oil injected into the cylinder—thus insuring high over-all efficiency.

No pulling of pistons, no scraping of valves, no needless wear.

The illustration shows an Ingersoll-Rand Type "PO" 50 B.H.P. oil engine driving a direct-current generator at the Burlington County Hospital, Lisben, New Jersey.

This is another installation where Ingersoll-Rand oil engines are cutting power costs in driving pumps, generator, compressors and line shafts.

Let our engineers show you how these simple, rugged engines will reduce *your* power costs.

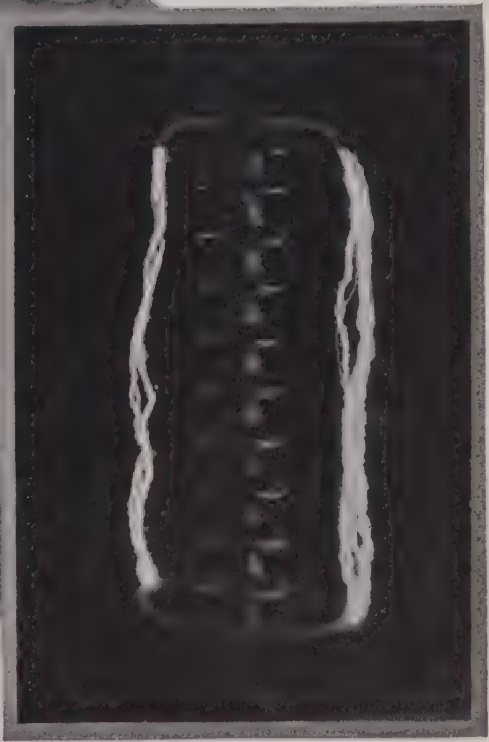
INGERSOLL-RAND COMPANY—11 BROADWAY, NEW YORK CITY
Offices in principal cities the world over
FOR CANADA REFER—CANADIAN INGERSOLL-RAND CO., LIMITED, 260 ST. JAMES STREET, MONTREAL, QUEBEC.

Ingersoll-Rand

Say you saw it advertised in the GENERAL ELECTRIC REVIEW

Do you want any insulators left after this happens?

This shows a heavy power arc following a lightning discharge on an unshielded string.



The Locke Grading Shield protects your insulators in this manner---------

LOCKE INSULATOR CORPORATION
BALTIMORE, MD. Factories at Victor, N. Y., and Baltimore, Md.
Sales Offices:

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Chicago, Ill.
770 Illinois Merchants Bank Bldg.
Atlanta, Ga.
414 Red Rock Bldg.

Salt Lake City, Utah
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Denver, Colo.
819 Seventeenth St.

San Francisco, Calif.
575 Mission St.
Los Angeles, Calif.
236 Los Angeles St.

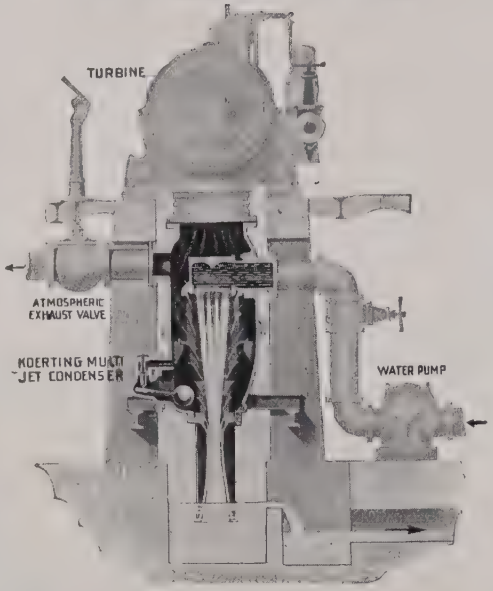
Portland, Oregon
61 Fifth St. North
Seattle, Wash.
570 Fifth Ave. South

Export Agents: International General Electric Co., Schenectady, N. Y.

LOCKE
PORCELAIN

Say you saw it advertised in the General Electric Review

SCHUTTE KOERTING



The water jets
do double duty

MULTI-JET CONDENSERS

operate without vacuum pumps. The water jets condense the steam and entrain the air. Send for Bulletin 5-A.

SCHUTTE & KOERTING CO.
1196 Thompson St. PHILADELPHIA, PA.

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WITH WIRING DIAGRAMS
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Automobile Starting and Lighting System—Ignition—Generation and Transmission—Electric Tools — Plant Management — Power Station Plans — ARMATURE WINDING—Armature Repairing —A.C. Motors—Alternator Construction — Alternators — D. C. Motors—Dynamos—Magnetic Induction—WIRING—Wiring Diagrams—Electric Lighting—Sign Flashers—Cable Splicing—Power Wiring—Underground Wiring—Outside Wiring—Wiring Finished Buildings—Tests.

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Here is an up-to-date, quick Ready Reference. It gives complete instruction and inside information on every electrical subject. Every point clearly explained in plain language and diagrams that are easily understood. Handy to use. Easy to learn from. Subjects arranged in progressive manner for the student and with complete index which gives information instantly to professional workers. A time saver, money saver, and a helping hand for Engineers, Professional Electricians, Students and all interested in electrical work.

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Audels Handy Book is a magnificent volume that you will be proud to own and carry with you. Gilt Edged. Durable real leather binding. 1040 pages of strong white paper. Large Type. 2600 illustrations and diagrams. A mine of information and a most unusual value at only $4. *Send no money.* Pay nothing to postman.
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Please send me AUDELS HANDY BOOK OF PRACTICAL ELECTRICITY for *free examination.* If satisfactory, I will send you $1 in 7 days, then $1 monthly until $4 is paid.

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Power Show

Exp. IV National Exposition of Power and Mechanical Engineering No. 2

CONTENTS

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A graphic display of the world's most remarkable achievements in power and mechanical engineering.

Hundreds of Interesting Exhibits!

The latest appliances for power generation, transmission and utilization, many in actual operation.

Where Big Business Meets

A vast gathering of prominent engineers, manufacturers, executives, all vitally interested in newer methods and better apparatus.

Why It Pays to Show Your Products

Make contacts with the important men who hold the purse strings of huge interests. Talk with customers, competitors, prospects. Exchange ideas. Build future business.

A Rich Opportunity

Benefit by the great educational features of the Show. There will be scores of interesting developments worth knowing about. Plan now to come.

How to Secure Desirable Exhibition Space

Write or wire for full information and reservations to

National Exposition of Power
and Mechanical Engineering

Grand Central Palace
NEW YORK CITY
NOV. 30th to DEC. 5th

Latest Development in Revolving Car Dumpers

It meets the demand for a dumper of simple construction, small investment, high efficiency, low operating cost and a minimum of labor.

Built in lengths of 30, 40, 50 and 60 feet for handling cars from 6 ft. 6 in. to 13 ft. 0 in. high and from 9 ft. 0 in. to 10 ft. 9 in. wide and loaded capacities up to 320,000 lbs. gross weight.

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Cleveland Electric Illuminating Co.
The Koppers Co. for Bethlehem Steel Co.
The Koppers Co. for Commonwealth Edison Co. (2 Plants)
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Chile Exploration Company (2 Machines)

The Wellman-Seaver-Morgan Company
Cleveland, Ohio, U. S. A.

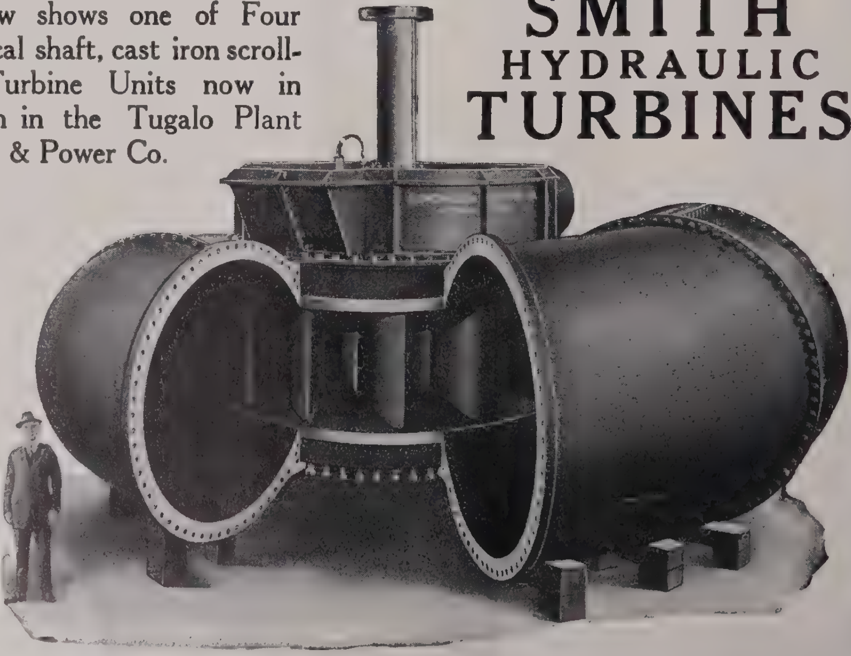
SMITH
HYDRAULIC
TURBINES

Accompanying view shows one of Four single-runner, vertical shaft, cast iron scroll-case Hydraulic Turbine Units now in successful operation in the Tugalo Plant of Georgia Railway & Power Co.

Each turbine develops 22,000 H.P. at 171.4 Rev. under 150 ft. head and is direct-connected to a 12,500 kw. General Electric Generator.

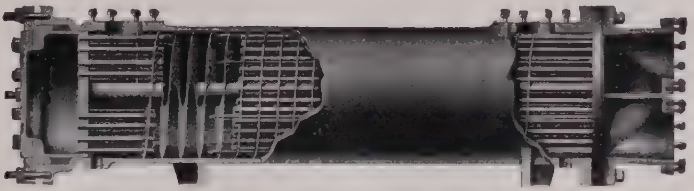
We have
The Experience,
The Resources, and
The Manufacturing Skill enabling us to render REAL SERVICE.

Ask our Dept. "G" for Bulletin of Designs and Data



S. Morgan Smith Co., York, Pa.

For cooler turbine bearings



The G-R Multiwhirl Cooler

efficient—compact—durable

Over 2000 in use

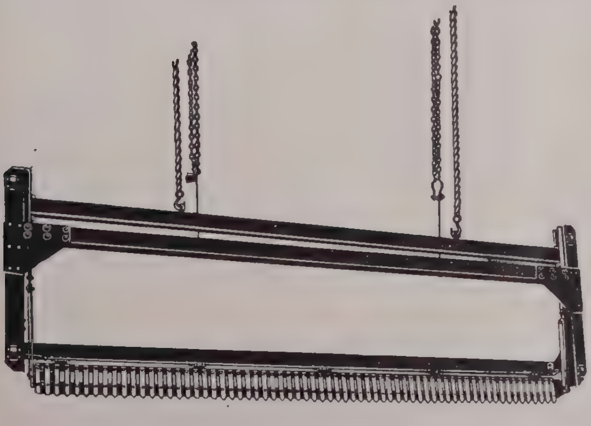
Send the coupon for full information

THE GRISCOM-RUSSELL COMPANY
2140 West St. Building, New York
BRANCHES IN PRINCIPAL CITIES

Name.........
Address.........
The Griscom-Russell Company,
2140 West Street Bldg., New York.
Gentlemen:
Please send us a copy of
bulletin describing the
G-R Multiwhirl
Cooler.
GER 10-25

NEWPORT NEWS RACK RAKE

WILL SOLVE YOUR TRASH PROBLEMS



Newport News Rack Rake in lowering position

How much tribute in the form of lost power and extra employees will you pay this fall to floating and submerged trash?

Write for full information about the Newport News Mechanically-operated Rack Rake, to suit your needs

NEWPORT NEWS SHIPBUILDING AND DRY DOCK COMPANY
DEPT. G.E. NEWPORT NEWS, VA.

Speaking of Fuel Saving—

The "RADOJET" Ejector Air Pump in its latest type with inter- and after-surface condensers saves fuel in two ways.

First, by building up and maintaining a higher vacuum.

Second, by using 50 per cent less steam than is ordinarily required to hold this higher vacuum.

The "RADOJET" has two stages. The steam from both is condensed by the main condensate and practically all of its heat is returned to the hot well. The air and gases from the condenser are compressed, reduced in volume and discharged into the atmosphere with the least possible expenditure of energy. The extracted air does not come in contact with the condensate. Hence, corrosion troubles are absent.

You can replace your less efficient air pumps with the new "RADOJET" Unit—irrespective of the make or type of your condensers.

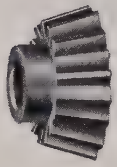
C.H.Wheeler Mfg.Co.

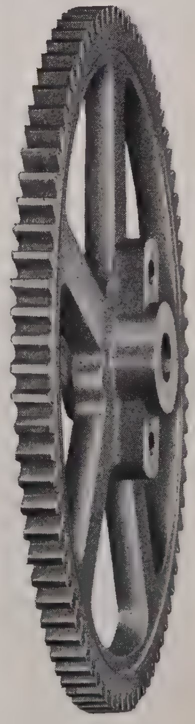
19th St., Lehigh and Sedgley Aves.

Philadelphia

"C. H. Wheeler of Philadelphia"

A die-casting talk with teeth in it





WHEN a man's teeth start to go to pieces, it doesn't necessarily mean the end of the teeth, and certainly not the end of the man. Therein a man differs from a gear. When a gear's teeth "go," good-bye teeth and good-bye gear. Even if it is only a baby gear, its first teeth are its last teeth. That's why, in buying gears, it pays to make sure that the teeth are strong, sound teeth.

Take the gears shown here. There's nothing false about their teeth. These gears were die-cast by us and in actual use have proved everything good gears should be.

If you have need of die-cast gears with stout teeth, or of other die-cast parts, you will find it to your advantage to learn of our complete die-casting service. Let our expert staff of technical men help you solve your die-casting problems.

When you buy die-castings from us, you are assured of the same high quality that has established our Dutch Boy trademark as a mark of excellence on babbitts, solder and paint materials.

NATIONAL LEAD COMPANY
Die-Casting Division
111 Broadway New York, N. Y.

Western Representatives: E. R. McCormick, 2599 Cadillac Ave., Detroit, Mich A. H. Bergedick, 667 Bowen Street, Dayton, Ohio. A. A. Gildemeister, 444 Fourth Street, Toledo, Ohio.

This is one of a series of advertisements describing some of the interesting and unusual uses of die-castings in various fields.

ALUMINUM, ZINC, LEAD *and* TIN

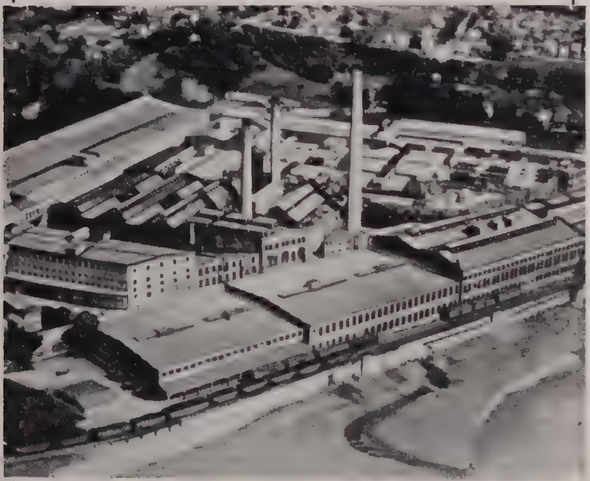
DIE-CASTINGS

"Buffalo" Fans help increase boiler output 66⅔%

William J. Lickert, Combustion Engineer, Champion Coated Paper Co., Hamilton, O., says:

"Expansion in our company—the largest manufacturers of coated paper in the world—requires changes in plant equipment amounting to $3,500,000. In our boiler room we now have sixteen 320-h.p. boilers, one 823 h.p., and one 1316 h.p.—a total of 7259 h.p.; all Stirlings. We are adding eight Stirlings of 823 h.p. and discontinuing the use of sixteen small boilers, which will give a total of 8723 boiler h.p.

"About 4½ years ago we changed our boilers from natural draft stoker feed to forced draft with underfeed stokers, increasing the boiler capacities from 150% of their normal ratings to our present 250%. This will give us 17,000 h.p. with our new boiler equipment.



"To furnish air for the forced draft, we installed a Buffalo Forge fan of 100,000 cu. ft. per minute capacity, with an interchangeable steam turbine and motor drive rated at 210 h.p. at 970 r.p.m. To furnish greater flexibility, we installed another Buffalo Forge forced draft fan of 90,000 cu ft. per minute, driven by a 150 h.p.-motor at 870 r.p.m.

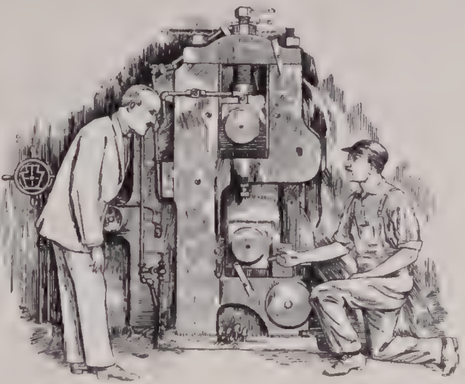
"When we have plenty of exhaust steam we operate the motor-driven fan; the turbine-driven fan is used when we don't have enough steam for our feed water heater. When our boilers are crowded we often use both fans.

"Our Buffalo Forge fans have given us such satisfaction that we're going to have 5 of them in our new boiler room—3 motor-driven, 2 turbine-operated."

BUFFALO FORGE COMPANY
170 Mortimer St. BUFFALO, N. Y.

Branches in all principal Cities

"Buffalo" *Mechanical Draft Apparatus*



They Counted the Cost

THE engineers in this plant did not deceive themselves. Their lubrication cost included an item of $3,600 per year for oil and another item of $1,200 for oiler's wages. It looked reasonable. But there was a machine that required four new bearings per month at a cost of $108, and another machine that involved a similar expense every two months. For years they had taken for granted the seeming necessity of these replacements because close clearances interfered with the regular application of lubricant and at the same time high temperature lowered its effectiveness. Their lubrication was really costing them $6,744 per year.

After some study they installed the Keystone Safety System and Keystone High Temperature Grease. A slightly heavier set of bearings was installed where conditions were worst. After three years of service the same bearings are still in use and apparently good for an indefinite run. The oiler's services are no longer necessary. He was transferred to productive work and one of the machine shop hands now turns down the lubricators once a day at no extra expense. $1,400 per year covers the cost of an adequate supply of high-grade lubricant.

The total cost has averaged $1,526 per year since the installation, and the engineers who counted the cost are now counting their savings at the rate of $5,218 per year.

The savings possible through the application of scientific lubrication methods are frequently startling to officials who have become accustomed to heavy lubrication expense. Your request will bring our booklets "Keeping Down the Cost of Lubrication" and "Densities and Uses of Keystone Grease" which contain valuable suggestions.

KEYSTONE GREASE

KEYSTONE LUBRICATING CO.
21st and Clearfield Sts. *Philadelphia, Pa.*
Established 1884
Branch Offices and Warehouses in the principal cities of the world

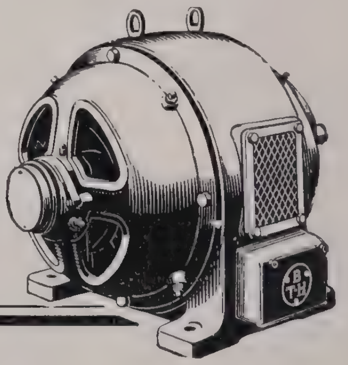
B T-H

Motors

Due to their low temperature rise and heavy overload capacity B.T.H. Motors give reliable service under the most arduous conditions. They are manufactured in all sizes over a wide speed range and can be supplied for either alternating or direct current systems.

The design of these motors is based on extensive experience of industrial drives of every description, and thus they are of extremely robust construction and give continuous service with minimum attention.

To assist in giving full information of the most suitable type of motor, kindly indicate the duty to be fulfilled.



The British Thomson-Houston Co., Ltd.

Electrical Engineers and Manufacturers

Owners for Great Britain and Ireland of all patent rights of the G.E. Co., U.S.A.

Head Office: Rugby, England. :: :: London, England: Crown House, Aldwych

Works: Rugby, Birmingham, Willesden, Coventry and Chesterfield

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Investment Bankers

are offered

Power and Light Securities

issued by companies with long records of substantial earnings.

We extend the facilities of our organization to those desiring detailed information or reports on any of the companies with which we are identified.

Electric Bond and Share Company

(Paid-up Capital and Surplus $70,000,000)

71 Broadway - - - New York

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

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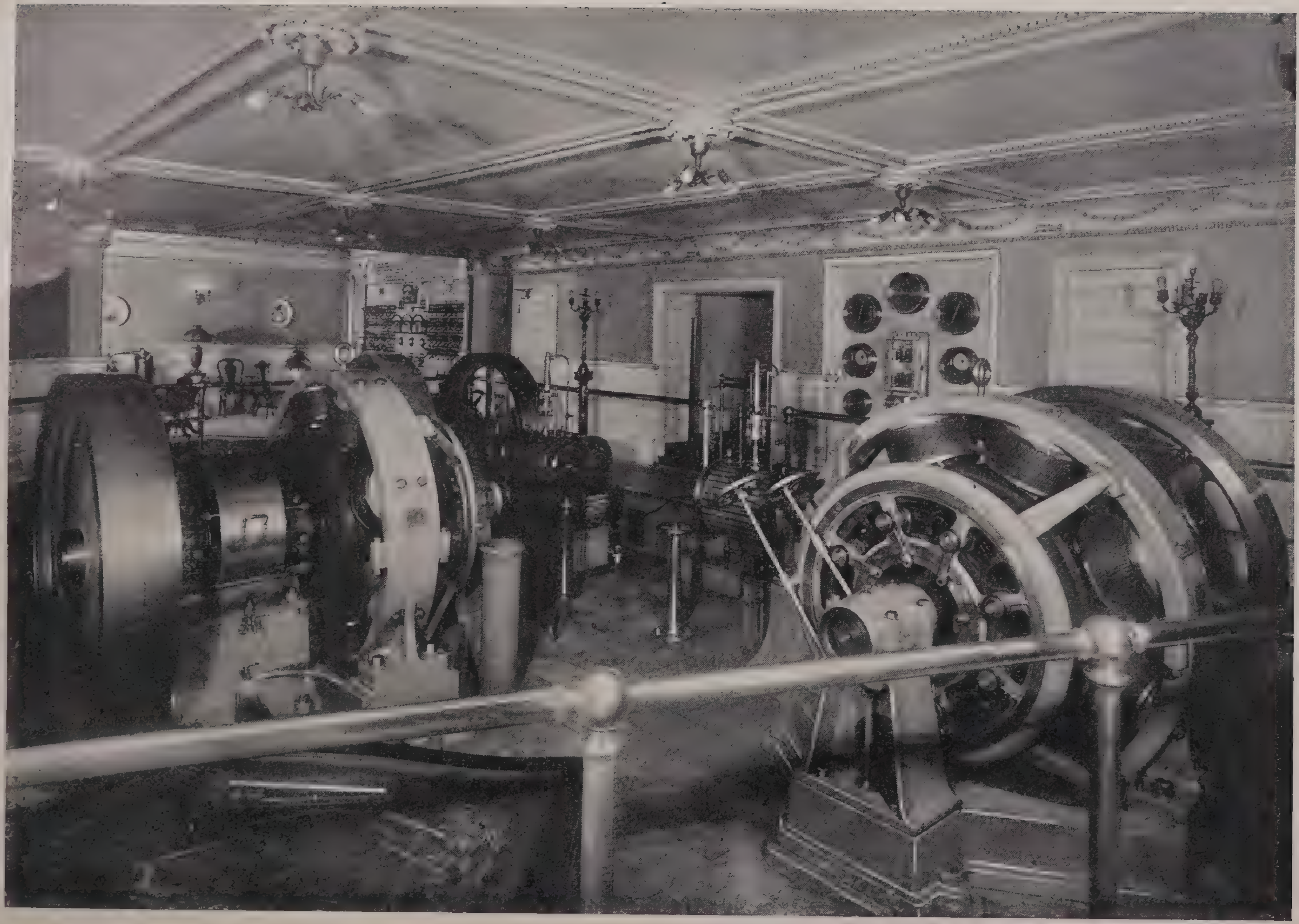


HOW DIFFERENT FROM THE MODERN TYPE OF POWER PLANT YET STILL IN SERVICE AFTER THIRTY YEARS

Compared with the plant shown on our cover, this one at Keith's Theatre, Boston, interestingly reminds us of the general trend in power production during this period: small isolated plants replaced by large central stations, steam engines by steam turbines, and low-voltage d-c. generators by high-voltage a-c. machines. Flywheels have

GENERAL ELECTRIC REVIEW

THE WORKMAN WHO IS NOT HANDICAPPED BY UNFAVORABLE SURROUNDINGS

Several weeks ago while in a store that was being remodeled but carrying on business, our attention was suddenly distracted from a contemplated purchase by the noise of nearby hammering. One glance to determine the cause of the interruption secured our forgiveness, for there was presented the comical sight of an exceptionally tall man and an unusually short one standing on a horizontal plank supported on wooden horses and together endeavoring to nail a piece of embossed sheet metal to the ceiling. The tall man, bent at knees and neck, was using a shoulder to hold one corner of his end against the ceiling and unable to look upward was trying to fasten the other guided by sense of touch. Meantime his short companion after several futile attempts had at last succeeded on tip toe in starting a nail and was now struggling to drive it home with his hammer grasped at the extreme end of the handle. Truly, they were an ill-matched pair.

After the first flush of amusement which naturally would not be shared by the contractor, we wondered what he would do about the situation when he came to see how the work was progressing. Obviously two alternatives or a combination of them were open to consideration; either to alter the working conditions to suit the men, or to replace the men by others better suited to the conditions. As another possibility he might permit the work to continue as before, because of not finding either remedial measure readily possible. In any case, there might very likely flash through his mind the wish that he could adjust the stature of these workmen; for who has not at some time wished that for a particular task he could decrease the width of a hand, lengthen an arm, or strengthen a back?

Pure impossible fancy of course when applied to the human body, yet how valuable would be the workman who could be arranged to suit any prevailing condition so perfectly as to enable him to carry on his work efficiently!

In electricity we have the workman that most nearly fulfills this specification. Assigned the task of delivering light, heat, or power, oftentimes all three, the work may be carried on at high voltage or low voltage, with direct current or alternating current single-phase or polyphase of high frequency or low frequency. The conditions encountered in practice usually make it desirable to employ a sequence of these forms, and the facility with which transitions can be made from one form to another makes readily possible the complete adaptation of this workman to all conditions having a bearing on his operation.

Most of us have long been acquainted with the electro-mechanical devices by which these transitions are accomplished; and more recently we have learned how certain of these changes can also be brought about through electronic vacuum tubes, as for example the rectification of alternating current to direct current. As an addition to this information, we present in this issue a description of how the inversion of direct current to alternating current can be produced by a new combination of these tubes and their accessory equipment, called the Inverter. E. C. S.

The Inverter

By D. C. Prince

Research Laboratory, General Electric Company

In the September, 1924, issue of this magazine, Mr. Prince contributed an article dealing with the tube rectifier and its characteristic wave-forms. In the present contribution the author has taken the rectifier circuit and inverted it, turning in direct current at one end and drawing out alternating current at the other. The new apparatus, consisting of pliotron tubes, transformers, reactances, etc., is known as the "Inverter" and offers a means of converting direct current into alternating without the use of any rotating machines.
—Editor.

The name "inverter" is used to denote the inverse of a rectifier, and covers an assemblage of transformers and thermionic valves of any sort used to convert direct current into single or polyphase alternating current. Such a combination possesses technical interest for the reason that if inverters can be developed in power sizes to have an efficiency and reliability comparable with rotating apparatus they will hold promise for the practicability of high-voltage direct-current transmission. With such tubes at the receiving end, the power might be supplied by direct-current generators in series or by rectifiers.

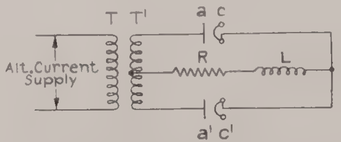


Fig. 1. Rectifier Circuit with Inductance in the Load

The ideal current and voltage relations in an inverter are practically the same as those in a rectifier, provided the inverter is supplying power to rotating apparatus which furnishes a sinusoidal counter e.m.f. These relationships were developed in an earlier article⑴ and will be reviewed far enough to show the similarity between inverter and rectifier characteristics.

Fig. 1 is a reproduction of Fig. 3 of the rectifier article, while Fig. 2 is a reproduction of Fig. 4. In Fig. 1 alternating current is supplied to transformer primary T. The secondary T' is connected to the rectifier anodes a, a', so that current flows from whichever is positive. The return circuit of both is by way of inductance L, which holds the current constant, and through load resistance R to the midpoint of winding T'. In Fig. 2, e_p and i_p are voltage and current waves in the transformer primary T, e_a and $e_{a'}$ are potentials of a and a' referred to the midpoint of T', i and i' are the corresponding currents, and e_R and i_R represent drop and current in the load resistance R. The cathodes c and c', which are tied together, have potential wave e_c following whichever anode is positive. The difference between e_c and e_R is the drop across the reactance L.

The ideal single-phase inverter circuit is shown in Fig. 3. It is assumed that the tubes have valve features permitting the interruption of current flowing from anode to cathode, but such features are omitted from the diagram for simplicity, and will be discussed later.

Fig. 3 is similar to Fig. 1 except that a direct-current generator G has been substituted for the load resistance R and a synchronous motor M replaces the alternating-current source.

When the motor rotates with its field excited there is an alternating potential established across T. At the anodes this electromotive force alternately opposes and adds to the voltage of generator G. If, during the time the potential at a opposes the generated voltage, the path ac is conducting and current flows, there will be a power input to the motor which will keep it revolving and

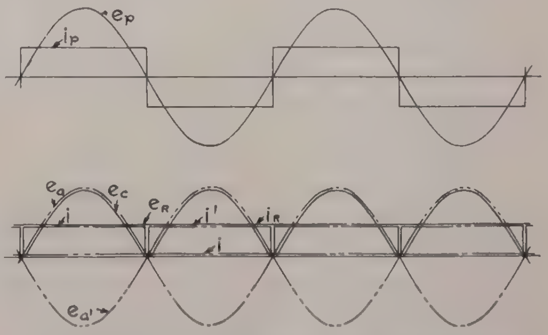


Fig. 2. Primary and Secondary Voltages and Currents of Rectifier Diagrammed in Fig. 1

e_p is the primary voltage, i_p the primary current. e_a and e_a' are the voltages of the two halves of the secondary winding. e_c is the cathode potential with respect to the center of the secondary winding. e_R is the load voltage, i_R the load current. i and i' are the secondary currents.

⑴ See D. C. Prince, "Rectifier Wave Forms," General Electric Review, Sept., 1924, pp. 608-615.

permit it to carry load. On account of the inductance L, the current flow is more or less constant. The voltage induced in L makes up the instantaneous differences between counter and impressed e.m.f.

Fig. 4 can thus be drawn as the equivalent of Fig. 2 for the inverter case, the upper curves representing conditions in the winding T and the lower curves representing conditions in the winding T'.

Referring to Fig. 4, i_p is out of phase with e_p by 180 deg., indicating that the impressed voltage is greater than the counter e.m.f. e_p, so that the current flows against e_p. For the winding T' an attempt is made to show the waves in a manner consistent with the connections; all potentials are measured with respect to the midpoint of the transformer winding. The positive terminal of the generator G is connected to the midpoint of the transformer winding T', the point about which a and a' swing. During the half cycle that $e_{a'}$ opposes e_G the path $a'c'$ is made conducting.

The current $i_{a'}$ then flows. Its magnitude is constant because of inductance L. It flows in opposition to $e_{a'}$ because e_G is enough greater than the average value of $e_{a'}$ to overcome the resistance losses in the wiring. At the instant that $e_{a'}$ and e_a cross, the path ac is made conducting and the path $a'c'$ is made nonconducting. The current i_a then flows, so that the total current i remains steady. The transfer can be made in zero time because the case used is ideal in that the transformer and motor are assumed to have no leakage inductance.

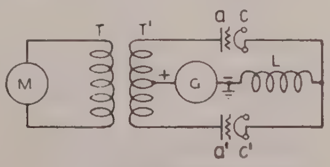


Fig. 3. **The Ideal Single-phase Inverter Circuit**

The cathodes c and c' alternately follow a and a' in potential, remaining below them by an amount equal to the tube drop. Their path is e_c. The potential difference between e_G and e_c is absorbed by inductance L. Since an inductance will absorb no unidirectional potential, areas included between e_c and e_G above and below e_G must be equal.

For the time being, in order to avoid unnecessary complications in the discussion, we will assume that there is a little devil who makes the paths ac and $a'c'$ conducting at exactly the right times. The requirements set up by transformer and motor inductance must be studied before his duties can be completely outlined. In Fig. 5, Fig. 10 of the previous article⁽¹⁾ is reproduced with only a slight change in the neighborhood of the time t_o.

In order to secure the highest set efficiency the tube losses should be held to a minimum. If current transfer from one tube to the other is forced by increasing the resistance in one, and decreasing it in the other, there will be resistance losses in the tubes during transfer. If both paths are made wholly conducting, and the current is caused to transfer naturally, all transfer loss may be avoided. During the time that both tubes are conducting, current will tend to flow in the circuit $T'acc'a'$, and by induction in circuit TM in response to the voltage generated by motor M. The voltage from G is neutralized entirely by the drop in inductance L, since the motor can furnish no counter e.m.f. at this point while both paths are conducting. This is so because of the symmetry of the winding T'. The induced voltages in both halves are equal and are entirely absorbed by equal impedance drops while both tubes are conducting.

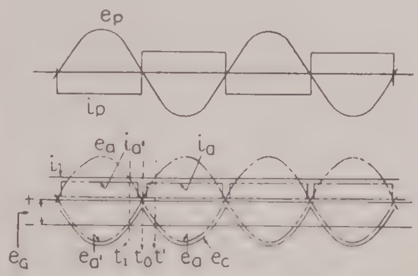


Fig. 4. **Primary and Secondary Voltages and Currents of Inverter Diagrammed in Fig. 3**

e_p is the primary voltage, i_p the primary current. e_a and $e_{a'}$ are the voltages of two halves of the secondary winding. e_c is the cathode potential with respect to the center of the secondary winding. e_R is the impressed voltage, i_R the load current. i and i' are secondary currents.

The current which would tend to flow is of the usual transient form shown by the dotted curve i, Fig. 5. In drawing this trace it is assumed that resistance is small compared with reactance, so that the current is nearly 90 deg. out of phase with the voltage producing it. The axis u approaches zero exponentially.

In the case of the rectifier the change in relative polarity of a and a' was in the proper direction to transfer the currents naturally beginning at time t_o, corresponding to the instant of zero induced voltage in the transformer, and ending at time t', but in that case it was proper for the current to be in phase with the alternating voltage. Now, however, it is desired to have the current flow in opposition to the alternating voltage. It is apparent from Fig. 5 that prior to time t_o current was shifting in the opposite direction. There should be a time t_1 at which the two paths might be made conducting with the resulting transfer as desired. At t_o the forces causing current change become hostile, so at this point, the path from which current has been transferred should be made nonconducting.

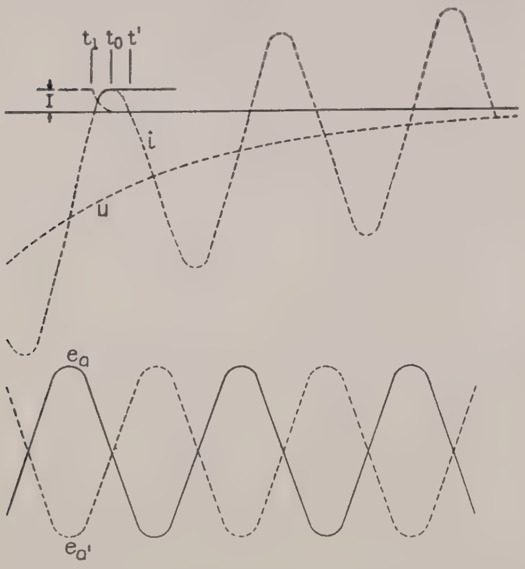


Fig. 5. Graphical Representation of Conditions Arising from the Supposition That the Transformer Shown in Fig. 3 Has Inductance

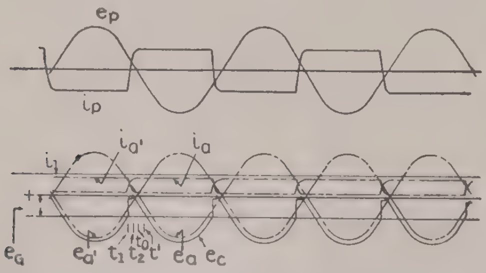


Fig. 6. Current and Voltage Waves Showing Effect of 26 deg. Period of Short Circuit During Which Currents Are Transferred and no Voltage is Produced by the Inverter

To put this proposition in another way: referring to Fig. 4, the two cathodes are following e_c and are approaching e_a at time t_1. Potential $e_{a'}$ is only sufficiently positive with respect to e_c to make the current flow, but e_a is very much more positive. At t_1, then, the path ac is made conducting and the potential difference between e_a and e_c is available to make current flow through ac in preference to $a'c'$. When t_o is reached, the current has all chosen the path ac. The path $a'c'$ is then made nonconducting so that the current can not return, although the forces are in the reverse direction.

As a matter of calculation, suppose that the voltage induced in motor M is sufficient to circulate a current whose peak is ten times the direct-current I, Fig. 5. Then, neglecting resistance, the period t_1t_o will occupy 26 deg. of electrical arc ($1 - \cos 26$ deg. $= 0.1$), so that a current whose amplitude is ten times normal will reach normal in 26 deg. The little devil is then instructed to open the gate at 26 deg. before zero hour and shut it at zero sharp.

It is important that he shut the gate at zero sharp, or even a little before, for safety. He may anticipate the 26 deg. however. If the transfer is commenced before time t_1 the current will all be transferred from path $a'c'$ to path ac before time t_o. At the termination of transfer there will still be a potential tending to make current flow in ac, in preference to $a'c'$, but current cannot reverse in $a'c'$ because the valves possess conductivity in only one direction. The current in $a'c'$ therefore remains at zero until t_o when the gate is closed.

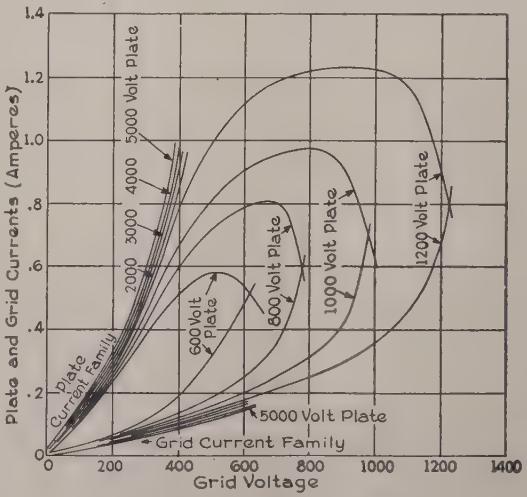


Fig. 7. Pliotron Characteristic Curves

If the path $a'c'$ were not rendered nonconducting at t_o, current would begin to flow again in this path. A three-electrode vacuum valve has the property of closing very positively, so that if it closes on a circuit carrying current, violent oscillations are almost invariably set up. It is important, therefore, that the current be brought to zero a short time before t_o and the valve be closed between that time and t_o.

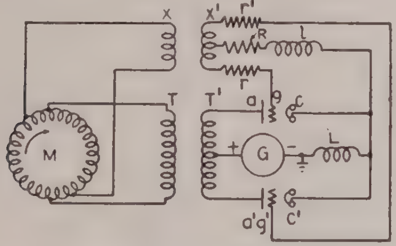


Fig. 8. Diagram of Inverter Showing Method of Deriving Grid Excitation

During the time that current transfer is taking place, the counter e.m.f. is the average of e.m.f.'s induced at *a* and *a'*. The difference is all consumed in the inductance of the windings. In the single-phase case this average is zero, but in polyphase cases it is not zero. If the time of transfer is ended before t_o, the counter e.m.f. becomes the potential e_a which is not in opposition to e_G until after t_o. There is, therefore, a time during which the inductance *L* must absorb more than the impressed direct potential. Fig. 6 corresponds to Fig. 4, but includes the effect of leakage reactance.

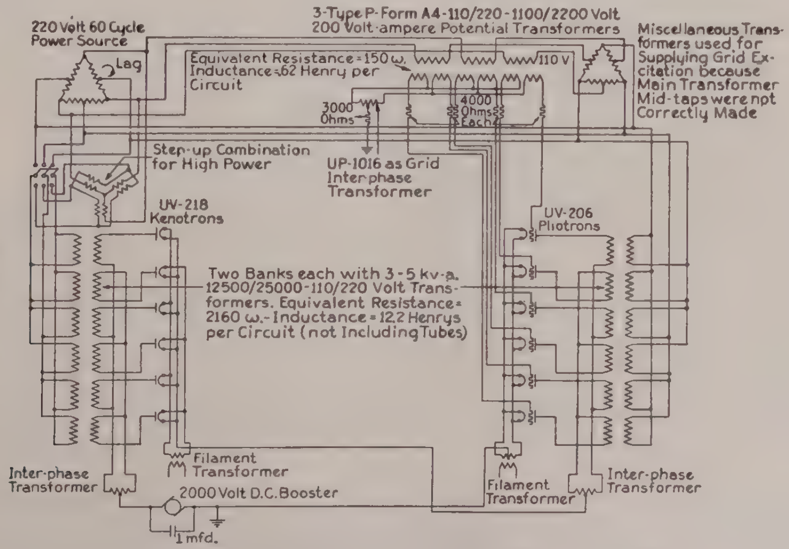

220 Volt 60 Cycle Power Source
Lag
3-Type P-Form A4-110/220-1100/2200 Volt 200 Volt-ampere Potential Transformers
Equivalent Resistance = 150 ω. Inductance = .62 Henry per Circuit
110 V
Miscellaneous Transformers used for Supplying Grid Excitation because Main Transformer Mid-taps were not Correctly Made
3000 Ohms
4000 Ohms Each
Step-up Combination for High Power
UP-1016 as Grid Interphase Transformer
UV-218 Kenotrons
UV-206 Pliotrons
Two Banks each with 3-5 kv-a. 12500/25000-110/220 Volt Transformers. Equivalent Resistance = 2160 ω.-Inductance = 12.2 Henrys per Circuit (not Including Tubes)
Filament Transformer
Inter-phase Transformer
2000 Volt D.C. Booster
1 mfd.
Filament Transformer
Inter-phase Transformer

Fig. 10. Circuit Diagram of 15,000-volt Rectifier and Inverter

At time t_1 (Fig. 6), path *ac* becomes conducting and current begins to shift from *a'c'* to *ac*. At t_2 the transfer is complete. Between t_1 and t_2, e_c was below the average of e_a and $e_{a'}$ by just enough to make current flow. By t_2 all the current is flowing in path *ac*, and e_c accordingly jumps to a distance below e_a just sufficient to maintain the current. Path *a'c'* is made nonconducting at some time between t_2 and t_o, but this does not produce any changes in the waves because no current is flowing in *a'c'*, and no current change is produced.

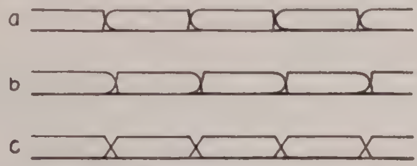


Fig. 9. Comparison of Current Waves

(*a*) Inverter current wave form
(*b*) Rectifier current wave form
(*c*) Grig current wave form

The foregoing discussion is general in that the type of valve device is unimportant. No matter what the means of cut-off, the conditions to be fulfilled are the same. The two paths involved in the transfer are both made conducting during a period when the voltage relations are right to produce the transfer. After the transfer is complete, the path carrying no current is rendered nonconducting. The only other requirement is that the paths possess unidirectional conductivity. Without this property the valve closing must be exactly timed and this is not possible in circuits where all the factors are fluctuating to some extent.

The grid of a three-electrode valve, or pliotron, may be controlled from the alternating-current circuit in such a way as to do the work of the little devil nearly as well as he can do it himself. Fig. 7 is a set of characteristic curves of a General Electric one-kilowatt pliotron. It is apparent that a rough proportionality exists between plate current and grid current, so that if we make certain that the grid of a tube is drawing current, then that tube is in a conducting state. As already pointed out, there is a close similarity between rectifier and inverter characteristics. The required grid potential changes resemble closely the normal potential changes of the anodes of a rectifier. We will then combine Fig. 1 and Fig. 3 into Fig. 8.

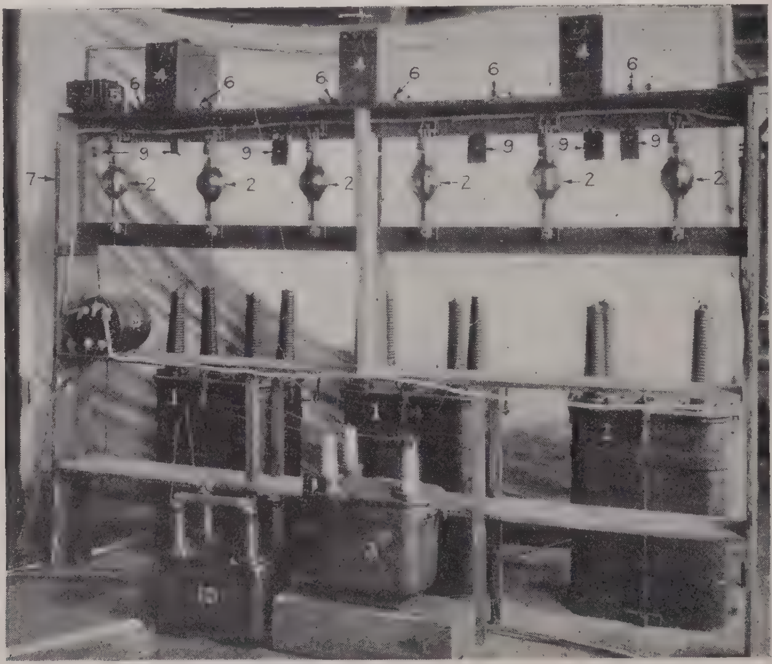


Fig. 11. Set Built for Laboratory Use

All the elements of Fig. 1 and 3 are here included, and, in addition, resistances r and r'. The grid transformer primary x is connected to points of the motor winding M so as to have a phase advance of a little more than half the time between t_1 and t_o. The purpose of resistances r and r' is best explained by reference to Fig. 9. Part *a* of this diagram gives the form which the main anode current waves will naturally take. On account of the proportionality between anode and grid currents, the grid current wave should approach this form as nearly as possible.

But an actual rectifier has a current waveform such as shown in Fig. 9-b. The transfer begins very gradually just when the maximum rate of change is required in the anode circuit. If the resistances r and r' are inserted, the two grids will begin to divide the current as soon as the potential difference between grids becomes equal to the $i_g r$ drop in the particular resistance carrying the grid current. The grids will continue to divide the current until the grid potential difference has reversed and reached the value equal to the $i_{g'} r'$ drop. If the resistances r, r' are large compared with the reactance in the grid transformer circuit, the transfer current will be similar in shape to the voltage during the transfer period, i.e., nearly linear for a sine wave near zero. The linear transfer as shown in Fig. 9-c is still not the same shape as the anode transfer in Fig. 9-a, but it may be made to have a sufficient initial slope for the beginning of transfer and an excess slope thereafter without causing excessive grid loss.

From Fig. 6 it appears that, due to the inductance of motor and transformer, the current and voltage in the alternating-current circuit are not exactly 180 deg. out of phase. This means that a wattless component must be supplied by the motor; that is, it must either be a synchronous motor, or must be associated with condensers to supply the wattless component.

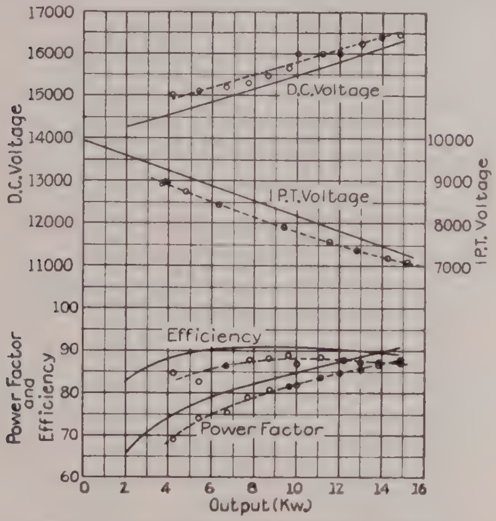
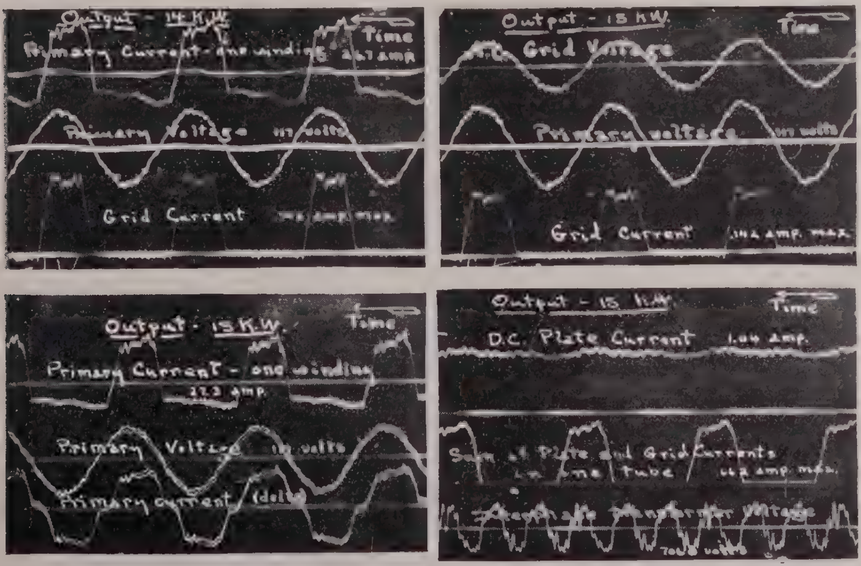


Fig. 12. Characteristics of Set Shown in Fig. 11

It may be objected that no means are given for starting the apparatus or for governing the speed after it is started. The criticism is well founded for the arrangement shown. However, arrangements of condensers and inductances will accomplish the same purpose, and at the same time be self-starting. Once oscillations are started power is available to start up motors and other rotating apparatus.

The frequency determining element in the arrangements shown is the synchronous motor *M*. Once this machine is rotating the direct-current drawn is determined by its counter e.m.f. If it slows down, the counter e.m.f. is reduced and more current is drawn until the speed is restored.

Fig. 10 is a connection diagram of a set figured along the lines suggested above. Fig. 11 is a photograph of the set built for laboratory use. Fig. 12 shows the characteristics of this set as determined by calculation and as observed experimentally. The performance on an absolute basis is not remarkable; however, the close correspondence between calculations and tests indicates that when tubes are developed to a stage comparable with other power apparatus, the practicability of high voltage direct-current transmission, with vacuum tubes in the converting apparatus, will probably not be far distant.



Typical Oscillograms of Inverter Performances

Matter—Is There Anything In It?

By Dr. Willis R. Whitney

Director, Research Laboratory, General Electric Company

Last month Dr. Whitney delivered before the annual convention of the American Chemical Society a paper on the composition of matter in which the information was presented in so entertaining a manner that we believe pleasure will be found in reading the following abstract of it. Striking experiments were performed to demonstrate the various phases of the subject, and a number of them are described in the article. Others, which are here omitted, were described in "The Vacuum—There's Something in It" which appeared in the July, 1924, issue of this magazine.—Editor.

The general subject of the composition of matter particularly interests chemists and physicists. Matter is now being so closely allied with electricity that it seems as though it might be helpful to review some of the modern disclosures. Of course no one knows much more about matter and its contents than experiments show us. The further we push these attempts at interpretation, the more difficult seems a complete explanation. The mechanical conceptions we have made in the past have helped us ahead, and new pictures promise new progress. There is nothing more interesting than this continual change in fundamental theories. We still stand about where the meta-physician did when he questioned the independent existence of energy and matter.

To the chemist the periodic system of the elements seemed a marked stage of improvement. For nearly 60 years it has been evident that all chemical elements vary in character in a periodic manner with increasing atomic weights. But attempts to attribute this to different concentrations of the lightest one could never be completely justified. They were evidently not simply more or less hydrogen. Gradually the atoms of different substances gave way to a new line of attack. Some of the heavier (or larger) were found to be disintegrating of their own volition into smaller charged particles, and others were decomposed electrically. While such work as Rutherford's shows that hydrogen and helium can be literally knocked out of many of the simpler elements, the heavier, like uranium, radium, and thorium, disintegrate spontaneously, emitting rapidly moving helium nuclei, electrons, and electromagnetic radiation, the end product of at least one radioactive series being lead.

Why do scientists persist in speculating and experimenting on the atom? First, because they are inquisitive. Every thing we know is made of atoms. There are only a very limited number of different kinds. These differences explain all differences we can probably ever know in our universe. Thus far, the more we have sought to understand them, the more we have gained in appreciation of an unexplored, unlimited territory of interest and service.

From the original atom of our youth, which was by definition indivisible, we now have spacious and divisible atoms. These differ from substance to substance. This difference is produced by increasing quantities of something already present in the smallest ones. Every teacher of chemistry used the discovery of scandium, germanium, and gallium, anticipated by the periodic law, to illustrate the value of orderly conceptions, even though he knew that good critical data seemed opposed to accepting any single protyl matter from which to make all elements. The persistent pursuit of this irregularity continued, and where blanks in the periodic system existed we always expected to find new elements. Three years ago the anticipated element hafnium was discovered by the x-ray method, in itself new. Much more recently we learned of the discovery of two more—masurium and rhenium—by the same agent. There are probably three more to be discovered.

But we have now reached a stage where a physical picture of the structure of atoms is more intricate than any earthly model, and more perfect geometrically than any known celestial system. The laws of astronomy have been called into play, and super celestial orientations are necessary to elucidate the complicated but not bewildering, the novel but not embarrassing, internals of the atoms. We go placidly from circular Copernican to elliptical Kepler orbits (Fig. 1) with actual enjoyment, and much quicker than we did in astronomy.

The electron has become the ultra atom. We cannot claim that ours is simpler than the atom of our fathers. Theirs was harder to pierce, but ours is harder to comprehend. The test is that our new atom has done many things for us which the old atom could not do.

Positive and negative charges, or protons and electrons, now account for all matter. Roughly speaking, the atom is a positive charge, with the equivalent number of negative charges spaced in and about it, and when, as by electrical means, we separate these positive and negative charges, we see them do just what we would expect such things to do. This new picture would be amply justified if it had done no more than lead to the removal of that terrible trouble we formerly had with fractional atomic weights. By merely photographing the action of electric and magnetic fields on the vapors of electrically conducting elements (Fig. 2) Aston showed that their relative weights are all whole numbers, or that they could all be constructed from the simplest ones.

It was in an experiment of Crookes that the new state of matter was found. He called it the fourth state, since it was not solid, liquid, nor gaseous. We now call it electronic. Almost every substance, particularly when heated, emits negative electrons, and these may be given almost any desired speed through space by the application of electrical fields. The presence of such ions and electrons in all sorts of conducting paths, or arcs, in air or gases had long been anticipated. It was natural to imagine that they originally existed in all substances. The work of J. J. Thomson and R. A. Millikan (Fig. 3) in recognizing, isolating, and, I might say, measuring and weighing the electron, can hardly be over valued, but cannot be described here. From it, and the work of other experimenters, we can make our new generalizations, the subject of this article.

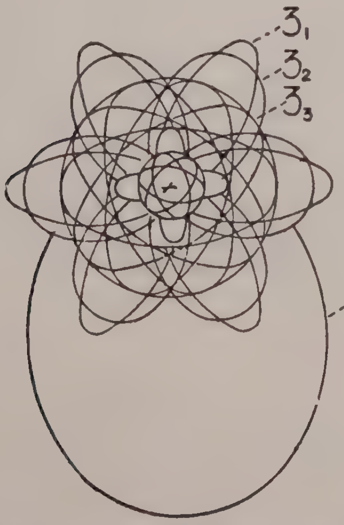


Fig. 1. The Structure of the Copper Atom as Proposed by Bohr, Showing the Orbits of the Electrons

Matter is at least not merely dry and hard, nor yet soft and wet. It is electronic and celestial, whatever that may mean, and the most we know about it is that it is almost entirely space. It is as empty as the sky. It is almost as empty as a perfect vacuum, although it usually contains a lot of energy. For example, a vacuum through which light is passing contains radiant energy. Apparently matter is only this same vacuum in which there are enormous numbers of positive and negative electric charges, which, however, occupy or fill only an exceedingly small portion of the space attributed to the matter. Novel and simplifying generalizations are interesting but dangerous, for, as someone has said, "no generalization in Nature is strictly true, not even this one." Nowadays we say that every gram of all matter consists of 6×10^{23} electrons and an equal quantity of positive electricity. Then we immediately start drawing conclusions. If it is true, then gravitation may be due merely to electronic concentration. But that is not all, because all things and their properties thus become electrical and differ by such old principles as come under the laws of Ohm, Coulomb, Gilbert, and Faraday. Tubes of force, those elastic bonds which Faraday saw binding every negative to its corresponding positive charge, still hold together electric units in the pictures of the modern atom.

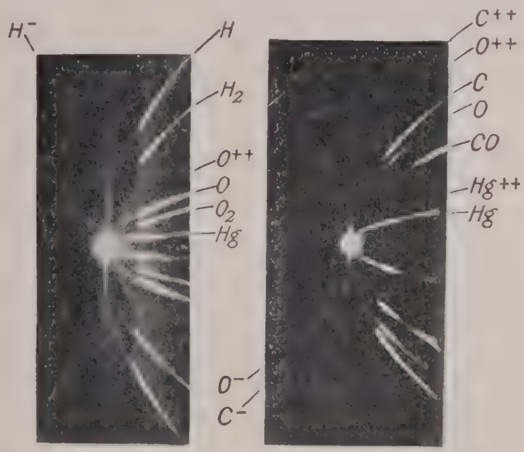


Fig. 2. Photographic Results Obtained by Aston When Electric and Magnetic Fields Were Applied to the Vapors of Ionized Gases

(Reproduced from Aston's "Isotopes" published by Edward Arnold & Co.)

The Crookes Tube

We shall first discuss a modified Crookes' tube, because much of our modern chemistry owes its clarity to his experiments.

At one end of a vacuum tube there is a small lamp filament which may be lighted. At the opposite, broader end there is a large metal plate coated with calcium tungstate. After the filament is lighted, high voltage is applied across the tube from filament to plate. The current passes through the vacuum and a glow spreads over the surface of the coated plate. Crookes knew that something existed in the path of this circuit within the vacuum. He called it the fourth state of matter. We call it the stream of electrons. We know it as a flow of negative charges coming from the hot filament. It might have been thought a disembodied electric current if the presence of electrons had not been disclosed. The stream has the properties of an electric current and of charged bodies. In this experiment a narrow metal band is wrapped around the outside of the glass bulb near the filament end. When it is charged with a negative voltage, as by merely connecting it to the high-voltage source, the effect of this stationary charge is to deflect the electrons of the beam, so that they are focused into the center of the tube. This greatly reduces the size of the spot of light on the plate.

When we bring a simple iron magnet near to the beam, but still outside of the vacuum, the path of the electrons is deflected by the magnetic field. This all accords with the assumption that negative ions, or electrons, liberated from the hot cathode or filament pass through the vacuum as individual charges. Their velocities depend on the voltage across the tube and their effects on striking the plate vary greatly with their velocity.

Our various chemical elements emit their electrons in different amounts, particularly when heated. In general, the higher the temperature and the greater the atomic volume, the greater this emission. Owing to the coating on the plate, we have fluorescence caused by the action of the bombarding electrons. If the voltage were raised across the tube, the character of the light emitted at this plate would also change greatly throughout a wide range of short wavelengths, even down to that of the naturally disintegrating elements, the gamma rays. In experiments of this nature Rontgen found the invisible but penetrating light we call x-rays.

Moseley found that the spectra, when different substances are used for this plate, showed a regular gradation in wavelengths as he proceeded from one chemical element to another. These so-called characteristic spectra are now a well recognized effect attributed to the electrons which lie nearest to the massive nucleus (the positive charge) of the respective atoms. These are disturbed by the high-velocity electrons of the cathode beam, and they produce light during their return to normal position in the atoms. As the atomic nuclei vary regularly in mass from one to another, so also the radiation effect due to these returning electrons gives us by the wavelengths of its spectral lines, a new periodic system of the elements. This is the Moseley system of the atomic numbers, and brings all of our elements, including the peculiar groups of isotopes discovered by Aston, into a system which is a great improvement on the previous periodic arrangement. The lightest atom has one electron outside of the positive center or nucleus, the second heavier element has two, the third, three, etc., throughout the whole list of elements.

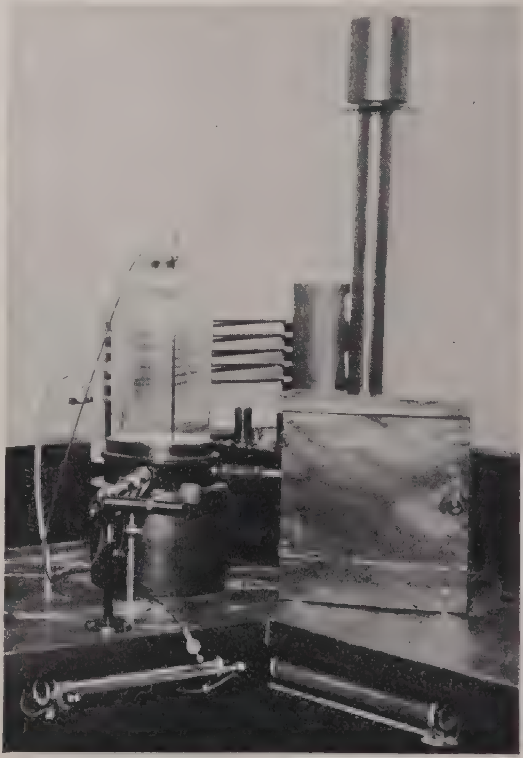


Fig. 3. Arrangement of Apparatus for Performing the Classical Oil Drop Experiment

Before describing an experiment which shows what is really the orderly decay of a chemical element into its electrical charges, we ought to discuss further this construction of the elements.

All the elements, from the smallest to the largest, including the isotopes, may be constructed by orderly assemblies of positive and negative electric charges. A slight correction in the case of hydrogen interests the physicist, but need not interfere with our simple picture. Atoms begin to look like solar and planetary systems with different groups of positive and negative charges at their centers, constituting a sort of sun or nucleus. This nucleus varies in charge or mass from element to element. Around this center group are the concentric systems of electrons, and the outermost groups of these determine most of the characteristic properties. For example, the hydrogen atom is one positive central charge and one negative electron in an orbit around it.

It may be worth while to picture it, because the other elements are compounds of the same elementary components. Possibly the dimensions given are still merely the outer dimensions of more empty space. Physicists have shot small projectiles through matter, so that we are convinced of its highly open-work structure. The projectiles were helium nuclei and electrons. The actual smallness of an atom is impossible to realize but so much seems known about its dimension that we must accept it and try to apply it.

A molecule of water contains two atoms of hydrogen. Suppose we start with one single drop of water and let all of its hydrogen atoms appear in turn as drops of water. How much of a rainfall must we picture in order to visualize all those hydrogen atoms of that drop? We know that the drop contains about 3×10^{21} hydrogen atoms. If these were as large as raindrops they could cover the whole world with a foot of water. Another way of expressing the raindrops which correspond in number to the hydrogen atoms in a drop of water is to say that if they fell as rapidly as in the heaviest rainfall, this rain would continue all over the United States for nearly two weeks.

Now, if we made one of these hydrogen atoms, which we used to think of as hard and indivisible, so large that it became a yard in diameter, its electron would still be only a pinhead in size, and its nucleus two thousand times smaller. So, while we might distinguish the orbit, its planet and sun would still be invisible. In other words, practically all of our first atom is apparently space. Between the two charges there is an electrical force holding them in position in the same way that gravity holds the four moons of Jupiter about that planet, for example.

The next lightest element to hydrogen is helium. This is a peculiar combination of positive and negative charges. It is not merely two positive charges in a nucleus and two negative outside, as one might expect for the second element. It is a peculiar product of crowding the charges, as though four hydrogens had been oddly squeezed together. When helium is once explained, then the other elements can be seen as similar arrangements of these two. The helium atom has four positive and two negative charges in the nucleus. Outside of this are the two other electrons necessary for a complete electrical balance. From helium through all the elements, we picture them as made one after another by the addition of positive charges to the nucleus, together with equivalent negative electrons; and, as this addition goes on, the positive nucleus itself increases in number of included negative charges, according to a simple system. For example, when we reach the largest electrical assembly, uranium, we find the nucleus as 238 positive charges and 146 negative charges. The other 92 negative charges necessary for balance seem to be outside the nucleus. These are now believed to be in concentric and elliptical orbits, more beautiful than celestial groups because they are more regular.

No attempt has been made here to draw a complete picture of the elements, and in order to account for the countless, but limited and orderly, combinations between elements, we need some additional sketch. The chemical properties of an element seem determined by those electrons which are in the far-flung or outer orbits of the atoms as those marked 3_1, 3_2 and 3_3 in Fig. 1. In other words, reactions are concerned with the contacts on the outside. It is the present view that in passing from one element to another in order of size, the added electrons occupy the outer orbits, and that "shells" or groups of 8 offer such a special type of stability that those that have 8 in the outer shell are self-satisfied atoms (the rare gases). They do not take part in chemical reactions, while all other atoms react with one another.

Elements with less than four electrons in the outer orbit act as though they want to reduce to zero, or to the 8 inside; while those having more than four react as if they want to become 8. This tendency is known as valency and the idea divides the elements into what were early called the positive and negative (or basic and acidic) groups. In this atomic tendency is seen the old chemical attraction; i.e., chemical affinity becomes electrical. Thus the existence of the stable substance sodium chloride is said to be due to the fact that the planetary system known as sodium has a single electron on its external orbit well outside the next inner orbits of 8 corresponding to neon, while chlorine has 7 such outer electrons, thus lacking one of becoming argon. In accord with our statement of valency, this makes them of equal valence. The compound (salt) may be said to be due to the sodium and chlorine planetary systems coming close together, so that the outer electron proceeds with heat evolution to embrace within its orbit both the nucleus of the sodium and of the chlorine. This new structure makes for greater electrical stability and gives us the impression of solidity, but the penetrability of the atomic orbits, the open-work structure, is about as before. For example, the absorption of x-rays for the elements is the same whether the atom occurs in the compounds or is free.

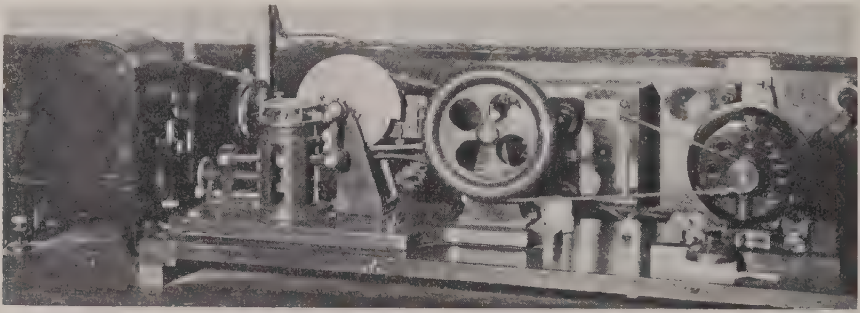


Fig. 4. Apparatus Used in Demonstrating the C. T. R. Wilson Ray Track Experiment

The most complicated or heavy elements are decaying fast enough so that the process is measurable. C. T. R. Wilson devised a simple method for making visible this decomposition. It is not simple to show this as an experiment. It is, however, so simple that it may be profitably described.

Excessive moisture in air is coagulated as fog on electric charges. The heavy elements, like uranium, thorium, and radium, are decomposing into positive and negative charges and radiant energy. In other words, they are shooting off what we call Alpha and Beta and Gamma rays. These particles, on passing through supersaturated air, produce lines visible to the naked eye, which lines are nothing but coagulated water vapor, or fog. Thus it is possible to count the rate of expulsion of these particles from the heavy elements, by watching the paths of fog which they produce. The apparatus used in this experiment is shown in Fig. 4.

It is also possible to arrive at the same result by audible means, using a modified form of Geiger's apparatus. The experiment consists in letting the moving charges ionize the air between charged electrodes in an enclosure. These successive ionizations may be detected by an amplifier system, and so heard on an ordinary radio loud speaker. The sound is due to an instantaneous flow of current between the electrodes—in this case a sharp platinum point and a plate. The potential across this space is about 1200 volts, or just below that required for simple electrical discharge.

The effect of each positive and negative particle may be separately indicated, because over the opening may be placed a screen which is opaque to the positive or Alpha particle, but not to the Beta, or negative electrons; or the Beta rays may be deflected by a magnetic field, leaving the Alpha and Gamma rays, unless the magnetic field is of enormous intensity, in which case the Alpha rays will also be bent away, leaving only the Gamma rays.

Decay of Elements

It is possible to listen to the disintegration of a piece of metallic uranium. This is equally possible with radium or thorium. While this decay gives audible evidence of its continuous occurrence, it is difficult to believe the truth, that after five thousand million years half of this little piece of uranium will have thus shot itself away, lost a few per cent of its weight, and left some metallic lead.

Frictional Electricity

Doubtless some of our simplest electrical experiments are chemical, and one is forced to ask himself whether, when the cat's fur is electrified by stroking it, the phenomenon is not due to removing some of the electrons from one of the substances to the other by the contact? This is not more strange than driving electrons out of metals by heat or light. The earliest division of electricity by the two-fluid conception gave us the two types, "vitreous and resinous electricity," or positive and negative, and the repellant effect of like charges and the attractive effect of dissimilar charges have long been known.

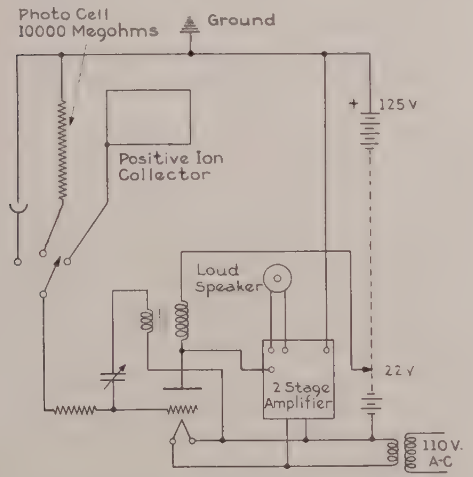


Fig. 5. An Ultra Sensitive Audio Galvanometer Whose Audible Response Can be Made Nearly Proportional to a Current as Small as 10^{-8} Amp.

Air Ions

There are many positive and negative charges in ordinary air. These are said to be due to the continual emission from decaying elements, like uranium and radium, and possibly also to the photoelectric effect of light. The number of pairs of positive and negative ions in normal atmosphere is about a thousand per cubic centimeter. This probably explains why air is not a better electrical insulator.

In the following experiment this ionized condition of the air is indicated, though perhaps it is not proved, because of the difficulty of insuring against current leakage through the apparatus. A square yard of copper gauze is suspended and made electrically negative by connecting it to one side of a direct-current source. As long as it is negative it will pick up the positive charges from the space about it, and thus will be a source of a very feeble current. This current is fed into a small condenser whose capacity may be varied at will. This condenser is in turn combined with a radio tube and loud speaker, so that the discharge from it may be heard after each filling, and we might thus measure the amount of current by counting the number of discharges per second. This is much like counting the number of quarts of water to determine an unknown volume. What we might call the electrical "hook-up" in this case was arranged by H. C. Thompson, and is shown in Fig. 5.

The musical note of the regular discharges indicates the rate of discharge. If, for example, it corresponded to middle C on the piano, it would indicate that the discharge rate is 256 per second. Knowing the size of our capacity, our electrical quart, we know the amount of the fluid.

This is a simple but very delicate method of measuring current, and we may use it first to show that there is a continuous current flow reaching the screen from the air or other sources which may be made to give different periods to the condenser discharge. To do this we merely alter the capacity of the condenser by turning the knob. The larger the capacity, or quart cup, the lower the rate of discharge. We may now superimpose on this steady current other currents of very small magnitude, and note the change in the rate of discharge.

Resistances

Suppose we draw on a piece of paper a long ink mark. When it is dry it has a resistance of many millions of ohms. This is connected to the screen and measuring device. If we take an ordinary piece of rubber insulated wire connected to earth, and hold the end in one hand, first by the rubber insulation alone, and touch the ink line on the paper with the other hand, we shall hear the changed note, indicating an increased current which has leaked from the earth through the rubber wire insulation, through the body, and through the long ink line to the screen.

If the finger is moved off the ink line, but is still held on the paper, the sound changes, and if we change the length of ink line included within the circuit we can imitate the musical notes of birds or sounds of other creatures. When the ink line is included and the resistance of the rubber cut out by taking hold of the naked wire, the frequency of discharge goes up greatly, as would be expected. In other words, this is merely a sensitive way of indicating small electrical currents.

Glass Leakage

When an incandescent lamp is lighted, a feeble current leaks across the vacuum and charges the glass negatively. This was early called the Edison effect, and in the case of a good vacuum the current is entirely due to the thermionic emission of the tungsten and the flow of the negative electrons to the glass. One naturally thinks of the glass as a good insulator at ordinary temperatures and a fair electrolyte when molten. When the bulb is held in the hand, the slight current which passes first across the vacuum and then through the cold glass to the hand may be measured by the delicate method just described.

When the lighted bulb is held in the hand in place of the wire formerly used, current is indicated, while, if the lamp is turned off, the indicator shows only about the usual unavoidable leakage current. If this lamp were held in the circuit grounded to earth through the body long enough, the current would finally produce a metallic deposit of sodium on the inside of the glass wall, due to electrolysis of the glass. Such a deposit may be seen occasionally on old electric lamp bulbs, due to the electron current acting through the vacuum for a long time.

Flame Ions

We now know that flames are sources of ions, and this may be shown by blowing the flame from a gas burner against the screen. Current will be indicated by the loud speaker. That this is due to the heated gases only is shown also by blowing the cold gas or air against the screen. Air from the surface of a heated wire is similarly ionized, and so this air, when blown against the screen, produces additional current.

Static

Suppose we take two rods of different materials. One is a synthetic insulator like amber, made by Professor Moureu, of Paris. The other is black rubber, or vulcanite. They merely happen to be convenient products for showing both vitreous and resinous electric charges.

When we rub the artificial amber with a piece of felt and approach the charged screen, a current is produced during the approach, but not during the recession. With the vulcanite rod, the reverse is the case. We may look at it as a case of induced currents, and so we get only the normal effect of moving the positive and negative charge in the direction to and away from the screen. As long as the charge remains on the rod, moving this about continues to produce the effect in the apparatus of a unidirectional current.

The apparatus is so constructed that it indicates only current flowing in one direction. The amplifying tubes, or radiotrons, in the circuit carry the current only when the negative ions can flow from the hot electrode of the tubes across the vacua. They thus act like check valves in a steam or water pipe.

Barkhausen Effect

Suppose we take a piece of iron wire about the dimensions of the graphite in a lead pencil and encase it in a small rubber tube, both to insulate it and make it more visible. Then suppose we bend the whole into a U shape, so that we may insert it into a pair of fine wire coils. These may be called exploring coils. They are connected to a delicate current-amplifying set and to a loud speaker. Any change in magnetism in the iron will then be communicated to us by the loud speaker.

Originally the wire was not magnetized. When we bring a permanent magnet near the small wire, the latter is temporarily magnetized, and this property is removed or it soon decays on removal of the large inducing magnet. The peculiar thing about this Barkhausen experiment is that it seems to show that the iron magnetizes by myriads of small units, or by jolts, and that it demagnetizes in the same way. This is true through the whole range of its magnetization. At every increment, as may be seen by bringing up the large magnet in steps, there is a noise, such as is usually made by very many sudden individual noises, and the greatest effect comes on the most complete reversals of the applied field. It looks as though multitudes of atoms, or atomic groups, were answering to the action of the large magnet. This corresponds in general with the assumption of induced orientation of a great many small continuous-current orbits, or small polar magnets. We do not know exactly what is taking place, but it must finally fit in with the fact that practically only iron and nickel are very magnetic and that they are composed of a certain collection and arrangement of electrical charges.

Experiments have shown that matter is electrical and that it is separable into its electrical charges. Moreover, whatever the electrical charge may be, it is spotted. In other words, it is localized in finite units at points in space. There seems for the present to be no cure for our belief that there are two kinds of electricity which we call positive and negative. Wherever these different kinds are stored in equivalent amounts, we have what we call ordinary or neutral matter, and the kinds of this matter depend on the numbers and space arrangements of these charged spots. Even as matter, they are still spread out so extensively that they closely resemble the starry heavens where distances measured in thousands of light-years separate the stars. But, just as our knowledge of the stars themselves is continually increasing, so we may be sure that we can go on extending our knowledge of electric charges.

Signal Lighting—A Special Problem

L. S. Dunham

Chief Engineer, Edison Primary Battery Division, Thomas A. Edison, Inc.

It does not at first seem reasonable that the light of a match may easily be seen at a distance of a mile on a dark night. That this is the case has proved very fortunate for the engineers who must design and build adequate and dependable signaling apparatus for railway service. By emitting narrow beams of light directed by a highly efficient optical system, electric bulbs as small as 0.4 candlepower can outshine the old-time oil lamp twenty to one. Mr. Dunham, who has been a pioneer in the application of electricity to signal lighting, here gives us some of the phases of the problems which our familiarity with ordinary lighting might lead us to ignore.—Editor.

During the last five years or so an interesting development in the use of miniature lamps for signaling purposes has been in progress which is not generally known. Much of the general interest of this development centers around two quite unusual factors which are closely related to each other. In the first place the requirements of a signal light appear to be totally different from those of general lighting. These differences grow out of the fact that a signal light is usually viewed directly and from a very restricted area, whereas general illumination is accomplished by flooding the field of vision so that the effects upon the eye are due, not to direct light, but to reflected light from the objects being viewed. By regarding the illuminated area in general lighting as a reflecting surface, it is apparent that the absorption losses are extremely great since the reflecting surface is very poor. Moreover, general lighting usually is expected to cover a wide angle about the light source, often requiring the use of diffusing glassware, whereas signals need seldom be visible through more than a very narrow angle, thus permitting the use of condensing lenses or highly efficient reflectors. The result is that the wattage or candlepower necessary to produce a good signal bears little similarity to that required for general illumination. A homely example expresses this fact very well. On a dark night it is perfectly easy to see the light from a match at a distance of a mile or more, yet the light emitted by the match is very slight. On the other hand, the amount of light necessary to illuminate a broad field of vision sufficiently to enable one to see the match being struck at a distance of one mile would be enormous, running doubtless into many million candles. This is the first rather remarkable factor of signal lighting which is of great importance, namely, that the wattages and candle powers required for general lighting are enormous compared with those necessary for signaling.

The second factor involves the source of energy and the electrical circuits employed in signaling. It is obviously necessary to have power for any electric lighting but this is more or less of a detail in most general lighting problems. It is merely a matter of leading commercial power to the lamps according to quite orthodox methods. In signaling, the matter of power and circuit arrangement is frequently extremely troublesome. Of course there are some lighted signals of such magnitude that separate power plants are provided for them and there are others in such locations that commercial power may be led to them readily. Those are rather special cases and this article does not refer to them. There are, however, thousands of lighted signals for which commercial power is virtually impossible (except at prohibitive costs) due to their location. Moreover, commercial power is subject to interruptions due to breakdowns, storms, etc. In thickly settled communities these interruptions are guarded against to such an extent that they do not frequently disturb the general illumination to a very alarming degree. Out in the wilderness, however, the hazards to commercial power lines are greater and interruptions ranging from a few hours to several days are not unknown. But even short interruptions in the operation of important lighted signals are of the greatest concern. The failure of several miles of railway signal lights, for example, is a very serious matter.

It is possible to guard against signal interruptions due to power interruptions by installing battery reserves and this is sometimes done. This is not a universal solution, however, because it still may require that power lines be strung at costs that are prohibitive. In rare cases, too, storage batteries may be used at the signals but transported to a charging station from time to time. This is not always practicable because the expense of attendance is often greater than all other operating costs combined. In the Northwest, for example, there are stretches of lighted railway signals that are practically inaccessible during winter months except by sending out a locomotive and car at great expense while certain other signals are not accessible at all during certain seasons.

These are factors which do not occur in general lighting but which must be reckoned with in signal lighting. Apart from these difficulties many signals are controlled through various relays. In some cases the lamp current passes no less than four relay contacts. This means that low wattages must be used because, if currents are high, IR drops are great and relay design troublesome or, if voltages are high, arcing and insulation difficulties creep in.

Thus, regarding the second important factor of signal lighting, we find that the matter of power supply and circuit conditions are entirely different from those of ordinary illumination. This, together with the first, which demonstrated the extremely low wattage or candlepower permissible in signaling, sets this service quite apart from the usual applications of incandescent lamps.

In spite of the fact that these considerations are entirely unusual to most electric lighting problems they are by no means unusual in signaling problems. Railways have been compelled to furnish limited amounts of electrical energy reliably and economically at scattered signal locations, and the alkaline primary battery has been an accepted standard for such service for many years. A suitable number of these cells constitute a separate power unit at each signal free from any connection with outside influences and capable of giving service practically without attention over long periods of time. These primary cells are quite different from storage cells in that they do not require recharging from a source of electrical energy. As they become exhausted, certain of the active parts are replaced and the cells thus restored to full value.

The first attack on the problem of electrically lighted signals (without reference to a limited number of extremely powerful beacons) was made in the field of railway signaling. This field was selected largely because railway signals were firmly established so that the problem was merely to substitute electric for the then standard oil lights and to apply the same primary cells that were already well known as a power source in other fields where reliable low-current supply was required.

Nevertheless this was not altogether a simple matter and a vast amount of development work was necessary in the design of proper incandescent lamps and new auxiliary apparatus. This early work was described in a joint paper by Mr. L. C. Porter, of the Edison Lamp Works, and Mr. F. S. Stallknecht, of Thomas A. Edison, Inc., presented at a meeting of the Illuminating Engineering Society at New York City in March, 1920, and in a paper by Mr. Stallknecht before the Signal Section of the American Railway Association at Albany, N. Y., in January, 1921.

The result has been that where oil lighted railway signal lamps were the standard practice not longer than five or six years ago it is now universally conceded that oil lighting is obsolete. Little, if any, new railway signaling is being installed without electric lights. The standard incandescent lamp for replacing oil lights on railway signals is a single-contact, bayonet-base lamp, rated at 3.5 volts, 0.3 ampere, operated by four alkaline type primary cells in series.

(For special reasons a lamp rated at 13.5 volts, 0.25 ampere is used on certain circuits to a very limited extent.) This lamp yields somewhat less than 0.4 candlepower in a horizontal plane, yet, when it is substituted for the old oil lamp, it yields a signal beam of roughly 20 times the intensity of the oil signal beam. By the use of a parabolic reflector with this lamp, a signal beam of an intensity about 30 times as great as the old oil signal beam is produced. Visibility of these signals up to three miles is by no means unusual and a range of five miles is quite possible in favorable weather.

Since the earlier days, a certain type of railway signal has been introduced in which there are no mechanical parts as in the older semaphore signals that were lighted with oil lamps. This is the so-called "light signal" in which the condition of affairs on the track is indicated to approaching trains by lights only, either by various colors or by various positioning of lights of the same color. These signals must be sufficiently intense to give clear signals in bright daylight. At first it was supposed that this could be done only by using relatively high wattages, and lamps up to 40 watts were employed. The trouble was, however, that no suitable power could be found and complications in auxiliary apparatus were great. In some cases storage batteries have been used and are still used but the real answer has been a continual reduction in lamp wattage, in part because experience has shown excessive wattage to be unnecessary and in part because great progress has been made on improved optical systems, but chiefly because such a course simplifies the power question by permitting the use of standard primary cells. At present 18 watts marks about the maximum used in such signals and 10 watts is rapidly coming into general use. The most recent development is a signal using slightly over 5 watts.

This tendency is quite contrary to that of general lighting where progress is marked by using higher and higher wattages. In signal work the effort is all toward the development of superior optical systems and to greater efficiency because progress in this direction has such beneficial and far reaching effects upon the remainder of the signaling system. The possibilities of such development and application are so great as to warrant a better understanding of them by everyone, particularly those who may be concerned with signal lighting but who are more familiar with the solution of general lighting problems.

At present a surprising extension of miniature lamp applications to various types of signals outside of the railway field is in progress. This includes highway work, marine signaling, aerial signals, etc. These new applications should be handled as special problems, with due regard to the signals, circuits, power sources, etc., and with the co-operation of signal specialists in associated industries, who have a wide experience in signaling service and who have contributed largely to the developments thus far. With such handling, signal applications will be capable of extensive development but they are otherwise susceptible of being seriously hampered by unwise or ill-advised attempts to apply lamps not suited to the service or not in keeping with other factors which are of minor importance so far as the lamps are concerned but are of compelling importance so far as the signals as a whole are concerned.

It is hoped that this article will give some general idea of a field of incandescent lamp application which is not generally understood to the end that it may be cultivated and fostered by all but yet recognized as a special activity meriting, and in fact requiring, the attention of those branches of the industry which are able to develop it carefully along the lines of sound signaling practice.

Various Methods of Synchronizing

PART I

By JOHN AUCHINCLOSS

SWITCHBOARD ENGINEERING DEPARTMENT, GENERAL ELECTRIC COMPANY

In the "good old days" of central-station operating the switchboard operator did not have any engine telegraph to communicate with the engineer. When it was time to put a machine on the line, he would brace himself and with one hand on the manually operated switch and his attention fixed on the synchronizing lamp, he would wave his other arm to signal the engineer at the throttle to raise or lower the speed. With this crude method of synchronizing there was many a "poor shot," but today, with the rotary synchroscope and other operating refinements, quick and accurate synchronizing is easily accomplished—a feature which is highly essential since the safety of many large and costly machines and uninterrupted service to thousands of customers depend on perfect synchronizing. In Part I the author presents a discussion of the facts that determine proper synchronizing and describes the method of synchronizing by lamps or by a voltmeter and by the electrostatic synchroscope. In Part II he will cover the rotary synchroscope, interlocks on switch control and methods of synchronizing transformers, converters and frequency changers.—EDITOR.

General

Prior to closing the paralleling breaker between two sources of polyphase alternating current it must be ascertained that:

(1) The phase rotation of both sources has the same sequence,

(2) The voltages of both sources are of equal magnitude, and

(3) These voltages are rotating coincidently in phase.

The first of these requirements need be considered only when the sources or systems have never before been paralleled, while the second and third must be satisfied as completely as is practically possible at every occasion on which it is desired to parallel the systems. If the two systems be considered as two three-phase generators, intended to operate in parallel upon a common bus, and if one of the generators be a new one which it is required to place in service, it becomes necessary, first of all, to compare the phase sequence of the new machine with that of the old.

Comparison of Phase Sequence

This may be readily accomplished by the method shown in Fig. 1. The phases, as numbered at the terminal board of the new generator, are temporarily connected to those poles of the paralleling breaker which, on the other side, are connected to corresponding phases of the bus, that is, machine phase 1 is connected to the same pole as bus phase 1, machine phase 2 to the same pole as bus phase 2 and machine phase 3 to the same pole as bus phase 3. The polarity of all the potential transformers should be the same, and care should be observed in connecting the lamps to insure that each pair is connected across corresponding phases of the new machine and of the old. With normal voltage on both machines the pulsation of the lamps should be noted. If they all become bright and dark simultaneously the phase sequence of the new machine is the same as that of the old and the breaker connections may be made permanent. If, however, one pair of lamps is bright when the other pair is dark the phase sequence of the new machine is the reverse of that of the old. To remedy this condition two leads of the new machine should be interchanged at the breaker. When this has been effected and the new machine again brought up to normal voltage it will be found that both pairs of lamps become bright and dark simultaneously and the breaker connections may be made permanent. Since the phase sequence of both machines is now the same, it is only necessary in synchronizing to determine the moment of phase coincidence of one phase of both machines, for at this moment the remaining phases must also occupy coincident phase positions.

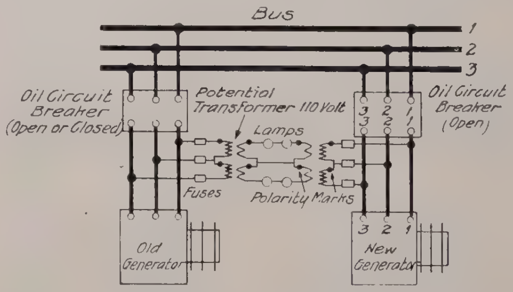

Bus
1
2
3
Oil Circuit Breaker (Open or Closed)
Potential Transformer 110 Volt
Lamps
Oil Circuit Breaker (Open)
3 2 1
3 2 1
Fuses
Polarity Marks
Old Generator
3 2 1
New Generator

Fig. 1. Connections for Comparison of Phase Sequence

Equality of Voltages

Equality of voltage may be obtained by means of the field rheostat of the new machine. It is advisable to read the voltage on all three phases to be sure that each phase winding is in condition to be connected to the bus.

At this point it might be well to investigate briefly the effect of closing the paralleling breaker when, other conditions being favorable, the voltages of the two machines are not equal.

Inequality of Induced Voltage with Coincidence in Phase

For the purpose of this discussion it is assumed that the paralleling switch has been closed, that both generators have the same rating, that they are supplying no power to the bus and that the field rheostats are so adjusted that different values of field amperes are supplied to each machine. Under these conditions the induced voltages of the machines will be as shown in Fig. 2 (a).

In this diagram E' is the induced voltage of the over-excited machine and E'' the induced voltage of the machine which is under-excited. E_m is the difference between the two at the bus. Now E_m is a voltage across the internal circuit between the machines, comprising the circuit of the two armatures in series. If for the sake of simplicity this circuit be assumed as wholly inductive then E_m will give rise to a current I_m lagging it in phase by 90 deg. I_m in turn will produce the flux ϕ in phase with it. Since the induced voltage is always 90 deg. behind the d-c. field flux which gives rise to it, it follows that the flux due to the d-c. excitation of machine E'' will be in phase with the flux ϕ due to I_m, so that the total magnetization of the machine generating E'' will be the *sum* of its d-c. field flux and the flux ϕ. Similarly the total magnetization of the machine generating E' will be the *difference* between its d-c. field flux and the flux ϕ, because the d-c. field flux of this machine, being 90 deg. ahead of E', will be opposite in phase to flux ϕ. This will be evident from a glance at Fig. 2 (b). In this figure ϕ' represents the d-c. flux inducing E' and ϕ'' the d-c. flux inducing E'', each flux being 90 deg. ahead of its corresponding voltage. It is clear from the diagram that the net effective flux in the machine generating E' is $\phi'-\phi$ while that in the machine generating E'' is $\phi''+\phi$. I_m, therefore, is simply a magnetizing current circulating through the circuit of both armatures in series, demagnetizing the over-excited machine and magnetizing the under-excited machine, thereby equalizing their voltages at the bus. Unlike the equalizing current of the direct-current generator, however, it has little influence on the load equalization of alternating-current machines. Load balance on such machines can be obtained only by varying the power supplied to their prime movers.

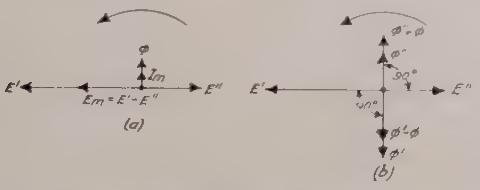


Fig. 2

(*a*) Conditions When Generated Voltages Are Unequal

(*b*) Combination of Flux to Equalize the Voltage at the Bus

To simplify the preceding discussion it was assumed that the armatures were devoid of ohmic resistance. While for the purpose of discussion this assumption is perfectly tenable, inasmuch as, compared to its inductive resistance, the ohmic resistance of the armature is very low, the resistance which it offers to the passage of the current I_m generates considerable heat. Since this heat is proportional to the square of the current and since it serves no useful purpose but actually reduces the capacity of the machines to carry useful load, it is highly undesirable. Since I_m is not a power current, however, its presence at the moment of synchronizing does no particular harm, provided that as soon as the machines have been paralleled it is reduced to a minimum by means of the field rheostats. For this reason small differences in voltage while synchronizing may be tolerated. In fact such differences are occasionally unavoidable in practice when the load, such as that of a railway system, fluctuates over wide ranges. With a fixed field on the incoming machine its induced voltage will vary as its speed is varied to follow the fluctuations in the speed of the system, so that at the moment the paralleling switch is closed the voltage of the incoming machine may not be quite the same as that of the bus, especially if the latter is held constant by means of a voltage regulator.

In large modern central stations the cross-magnetizing current which might circulate between the alternators is minimized by the use of individual automatic voltage regulators. These regulators control the generator field current by operating on the field rheostat of each generator's individual exciter. These exciters are not connected in parallel. The connections to the regulators are arranged in such a way that the position of the plunger of the a-c. magnet is partially controlled by the current from a current transformer connected in quadrature with the current of the potential transformer energizing the potential coil, as shown in Fig. 3. Since at unity power-factor the current from the current transformer is displaced 90 deg. from the current of the potential transformer, it has no component in phase with the potential transformer current and consequently exercises no effect upon the position of the magnet plunger which is then controlled by the potential transformer current only. If, however, there should be a tendency for one machine to alter its voltage above or below the common voltage of the other machines, a cross-magnetizing current will flow from the armature of the high or low voltage machine through the armatures of the normal voltage machines. Being a quadrature current this cross current is in phase on the magnet with the current from the potential transformer and, therefore assists or resists the pull of the latter upon the plunger. Its net effect is to increase or decrease the d-c. excitation of the abnormal machine until the cross magnetizing current has disappeared. By this means the appropriate d-c. excitation of all the machines may be maintained and magnetizing currents reduced to a minimum. It might be added that if the general power-factor of the system is on either side of unity a certain component of the system current will be in phase with the potential transformer current on the magnet, but as this component will be relatively the same for each of the regulators, its effect will be the same on all the generators connected to the bus.

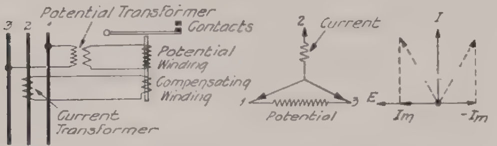


Fig. 3. Voltage Regulator Functioning to Reduce Cross Currents Between Generators

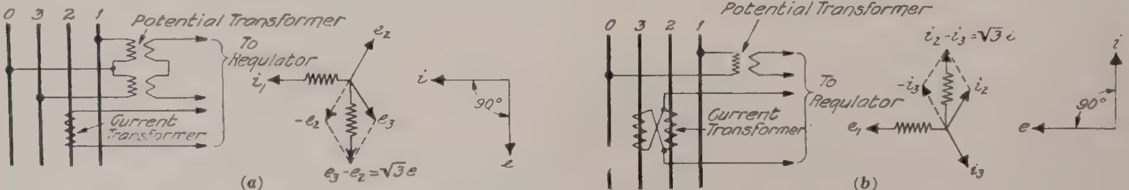


Fig. 4. Connections for One Potential and Two Current Transformers for Minimizing Cross Currents

In general, the quadrature relationship for this method of regulation is obtained by connecting the potential coil across the phase opposite to the line in which the current transformer is connected. In so-called "isolated phase" systems, however, in which it is not desired to connect potential transformers across phases, the quadrature relationship may be obtained in either of two ways, viz: Two potential transformers may be connected from line to neutral, or from line to ground, as the neutral is generally grounded, and the magnet coil connected across the two ends of the secondaries as shown in Fig. 4 (a). The current should then be taken from a current transformer connected in the remaining line. To avoid special magnet coils the potential transformers, when so connected, should each give a secondary voltage of $\frac{110}{\sqrt{3}}$ or 63.5 volts so that the total voltage on the magnet will be $63.5\times\sqrt{3}$ or 110 volts, or, if this is not feasible, a suitable resistor may be connected in series with the potential coil to reduce the voltage to the required value.

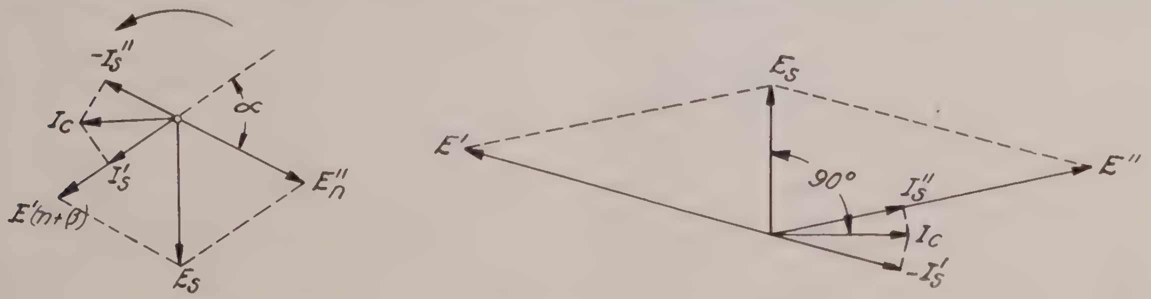
Another way of arriving at approximately the same result is to take the resultant of two cross-connected current transformers with the voltage to neutral of the remaining phase as shown in Fig. 4 (b). In this case the potential transformer should give 110 volts across the secondary while the current transformers should be about twice the normal ratio, or of a primary rating about twice the rating of the circuit to reduce the $\sqrt{3}$ increase in the resultant current to the normal 5 amp.

Having seen that, at the moment of paralleling, difference in voltage is practically harmless it may be in order here to take up the corresponding phenomena arising from difference in phase.

Equality of Voltages with Non-coincidence in Phase

Referring to Fig. 5 (a) let $E'_{(n+\beta)}$ be the voltage of the running machine rotating at the electrical speed $n+\beta$, and E''_n be the voltage of the starting or incoming machine rotating at the electrical speed n and behind $E'_{(n+\beta)}$ by the angle α which angle is *increas-*

ing at the rate $\frac{\beta}{t}$. If at this moment the throttle of the prime mover driving E''_n be slightly opened so that the electrical speed of this unit increases to the value $n+\beta+\gamma$ then α will *decrease* at the rate $\frac{\gamma}{t}$. Suppose now that the throttle is gradually closed again so that while α is decreasing, its *rate* of decrement is also decreasing until at the moment α becomes zero γ also becomes zero. The electrical speeds of both machines are now equal, being $n+\beta$ and their voltages are exactly in phase opposition with regard to the internal circuit between them. At this moment the paralleling switch may be closed without any interchange of synchronizing power between the machines. Unfortunately, however, attainment of exact synchronism is not always possible within the time usually available for the synchronizing operation. In the majority of cases, when the paralleling switch is closed, α and β or γ have appreciable values and our next step will be to investigate the phenomena arising from this condition.



(a) (b)

Fig. 5. E. M. F's. Equal in Magnitude but Differing in Phase Cause Components of the Cross Current to Pull the Machine Into Step

Returning to Fig. 5 (a), we find, at the instant shown, that the voltage difference between $E'_{(n+\beta)}$ and E''_n referred to the internal circuit between the machines is the voltage E_s.

In Figs. 2 (a) and 5 (a) E_m and E_s respectively are pressures exerted across the circuit of both armatures in series and since the voltages are in quadrature the currents arising from them must also be in quadrature. Also, if the current I_m is a magnetizing current the current I_c arising from E_s must be a power current. This is evident from Fig. 5 (a) in which it will be seen that I_c has a large positive component I'_s in phase with the machine voltage $E'_{(n+\beta)}$ and a corresponding negative component I''_s in phase with the other machine voltage E''_n. The power $E'_{(n+\beta)} I'_s$ is positive and must be generated by the machine which is ahead in phase while the power $E''_n I''_s$ is negative and is absorbed by the machine which is behind. The net effect is to slow down the fast machine represented by $E'_{(n+\beta)}$ and to increase the speed of the slow one represented by E''_n thereby decreasing the angle of displacement between the two voltages and also the synchronizing voltage E_s. At the moment of exact synchronism the synchronizing voltage E_s and with it the synchronizing current I_s disappear but as shown in Fig. 5 (b) the momentum of the two systems causes a certain amount of overshoot. Following the overshoot, that which was the leading machine now becomes the lagging one and vice versa. The synchronizing voltage E^s and its power currents I'_s and I''_s again come into play arresting the overshoot and pulling the machines back into step. After several such swings of gradually decreasing amplitude the machines if undisturbed by their prime movers will quickly settle down to synchronous operation.

Since the value of I_s depends upon the magnitude of E_s and since E_s in turn varies with α it follows that if α is very large, even though β and γ are small, I_s will also be very large, and considerable disturbance may accompany the closing of the paralleling switch. If the switch is closed when α is too large, the sudden speed change may result in such damage as twisted shafts and dislocated armature bars.

Similarly if β or γ were very large and α were small, or in other words, if the paralleling switch were closed at a time when there was considerable difference in the electrical speeds of the two machines as they passed through the synchronous position, the tendency to overshoot would be so great that, at the first swing, α might become large enough to cause damage. If, as previously stated, the switch is closed at the moment when α and β are both small, the value of I_s is correspondingly small and there is little or no strain. Since, I_s is a power current accompanied by severe mechanical stresses it is much more dangerous than the simple magnetizing current I_m and its magnitude should consequently be kept within small limits.

The idea seems to be rather prevalent that the worst condition for paralleling is at the moment when the machines are 180 deg. out of phase. While it is true that at this instant the synchronizing voltage E_s is a maximum, being the arithmetical sum of both machine voltages, the current I_c arising from it is also a maximum and has no component (assuming again a wholly inductive circuit) in phase with the machine voltages. The synchronizing power of each machine at this moment is $EI_c \cos 90$ deg. or zero, as shown in Fig. 6 (e). It may also be seen that at the moment of exact synchronism shown in Fig. 6 (a), the synchronizing power is again zero since there is no synchronizing voltage. At intermediate points, such as 120 deg. displacement, the synchronizing power of each machine is $\sqrt{3}\, EI_c \cos 60$ deg. or 0.866 EI_c; at 90 deg. displacement it is $\sqrt{2}\, EI_c \cos 45$ deg. or EI_c, while at 60 deg. displacement it is again $EI_c \cos 30$ deg. or 0.866 EI_c. Tabulating these values as shown below it is apparent that they pass through a cycle from zero through a maximum to zero again.

Displacement Angle	Synchronizing Power
0 degrees	0
60 degrees	0.866 EI_c
90 degrees	EI_c
120 degrees	0.866 EI_c
180 degrees	0

To determine this maximum we may proceed as shown in Fig. 7. In this diagram α is the displacement angle between the machine voltages, E_s is the synchronizing voltage, and I_c the cross current arising from it. Then assuming that the machine voltages are equal, $E' = E'' = E$; we may write

$$I_c = \frac{E_s}{Z}$$

where Z is the impedance of both armatures in series. Since Z is constant we may also write

$$\frac{E_s}{Z} = K \cdot E_s \tag{1}$$

and as the triangle $O\,E'\,E_s$ is isosceles

$$\frac{E_s}{Z} = E \sin \frac{\alpha}{2}$$

$$\text{Therefore } E_s = 2E \sin \frac{\alpha}{2} \tag{2}$$

Substituting $2E \sin \frac{\alpha}{Z}$ for Es in (1) we have

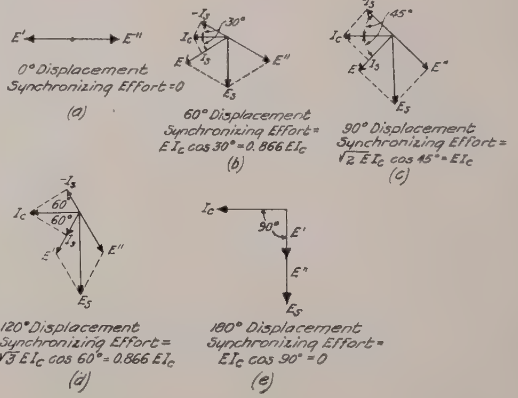
$$I_c = K \cdot 2E \sin \frac{\alpha}{2} \tag{3}$$

The synchronizing power is

$$P_s = I_c\, E \cos \frac{\alpha}{2} \tag{4}$$

which, substituting $K \cdot 2E \sin \frac{\alpha}{2}$ for I_c in (4), becomes

$$\begin{aligned} P_s &= K \cdot 2E^2 \cos \frac{\alpha}{2} \sin \frac{\alpha}{2} \\ &= K \cdot 2E^2 \frac{\sin \alpha}{2} \\ &= K \cdot E^2 \sin \alpha \end{aligned}$$



0° Displacement Synchronizing Effort = 0
(a)

60° Displacement Synchronizing Effort = $EI_c \cos 30° = 0.866\, EI_c$
(b)

90° Displacement Synchronizing Effort = $\sqrt{2}\, EI_c \cos 45° = EI_c$
(c)

120° Displacement Synchronizing Effort = $\sqrt{3}\, EI_c \cos 60° = 0.866\, EI_c$
(d)

180° Displacement Synchronizing Effort = $EI_c \cos 90° = 0$
(e)

Fig. 6. Synchronizing Effort Exerted at Various Degrees of Phase Displacement

Obviously $K \cdot E^2 \sin \alpha$ has its maximum value when $\sin \alpha = 1$, that is, when $\alpha = 90$ deg. The synchronizing power or corrective effort is therefore greatest when the machine voltages have a displacement of 90 deg.

Of course, although two generators running at equal speeds but paralleled 180 deg. out of phase have no synchronizing power, they cannot remain stable in that position, which virtually amounts to a short circuit across the terminals of each machine. At the first slight variation in the speed of either one of them a component of the enormous cross current will come in phase with the machine voltages. The power so developed will immediately increase the discrepancy in the speeds tending to draw the machines into synchronism. When the 90 deg. position is reached this power, as we have already seen, will be a maximum, but its effect is to accelerate and retard an acceleration and retardation already in progress. On the other hand, were the machines paralleled when running at equal speeds but at 90 deg. phase displacement, the maximum synchronizing power would be applied at a time when no acceleration or retardation were in progress. In other words, when paralleled at 180 deg. displacement, the maximum corrective effort is applied gradually and the rate of change of motion is also gradual, whereas when paralleled at 90 deg. displacement the maximum corrective effort is applied instantaneously and the change in relative motion must take place more rapidly. Since mechanical shock is a function of mass and acceleration, it follows that the stresses are more severe when the machines are paralleled at 90 deg. displacement than when they are paralleled with a displacement of 180 deg.

It should be remembered, however, that at 180 deg. displacement although the synchronizing power is zero the cross current is enormous, particularly if the machine is connected to a large system of low impedance. In this case the double voltage is opposed only by the impedance of the incoming machine and the current, consequently, may be much greater than that arising from a simple short circuit across the machine terminals. Even though shaft stress is absent, the mechanical stresses arising from the interaction of this current and the field flux are very severe.

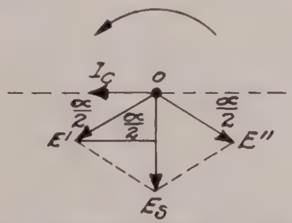


Fig. 7. Arbitrary Displacement Angle Assumed to Determine the Maximum Synchronizing Effort

Synchronizing with Lamps

There are several methods of synchronizing with lamps. When an individual lamp is mounted on each generator panel directly before the eyes of the operator, the method shown in Figs. 8, 9, 10 and 11 may be followed. With the connections shown in Figs. 8 and 10 the machines are in exact synchronism when the two lamp filaments are glowing at maximum brilliancy. At the same instant, when connected as in Figs. 9 and 11, there is no current in the filaments and the lamps are, if such an expression be permissible, at the moment of maximum darkness. Since there are several electrical degrees during the period of "maximum darkness," synchronizing with dark lamps is more a matter of guess work than actual determination. For example, the machines may be coming together into the sector of darkness, but, instead of continuing to approach after entering this sector, they may separate again and the operator, expecting the approach to continue, may close the paralleling switch before the separation had carried far enough to bring the lamp voltage again into the sector of illumination. Such action, if the separation were rapid, would constitute a "poor shot."

On the other hand, were the bright lamp method shown in Figs. 8 and 10 in use, the filaments would be at maximum brilliancy, but as the double voltage across the lamps would be travelling along the crest of its wave, any change in the relative phase displacement of the machines would have only a slight effect upon the brilliancy of the lamps. A comparison of the two methods is shown in Fig. 12 (a). In this diagram E' and E'' represent the running and starting voltages, respectively, displaced by the angle α. $E'-E''$ or E_b is the resultant voltage across the lamps when connected as shown in Figs. 8 and 10. E_b is $\frac{\alpha}{2}$ deg. behind E'. $E'+E''$, or E_d the resultant voltage across the lamps when connected as in Figs. 9 and 11, is $90-\frac{\alpha}{2}$ deg. ahead of E' or 90 deg. ahead of E_b. E_d, therefore, varies with the sine of α while E_b varies with the cosine. Now as α becomes small, corresponding to the synchronous position, the value of the sine changes much more rapidly than the value of the cosine for the same change in α. It is clear that for any change in the phase positions of the machines when near synchronism that there is a much greater change in the voltage across the lamps when connected as in Figs. 9 and 11 than when connected as in Figs. 8 and 10. This difference is shown in Fig. 12 (b) and constitutes a very strong argument in favor of synchronizing with the dark lamp. But while it is undeniably difficult to detect the moment of maximum brilliancy, due in part to the relatively small change in resultant voltage arising from change in phase displacement, and in part to failure of the eye itself to respond to such slight changes, it must also be admitted that to detect, not guess, the exact moment of maximum darkness over a period when no filament illumination is visible is also a rather difficult feat.

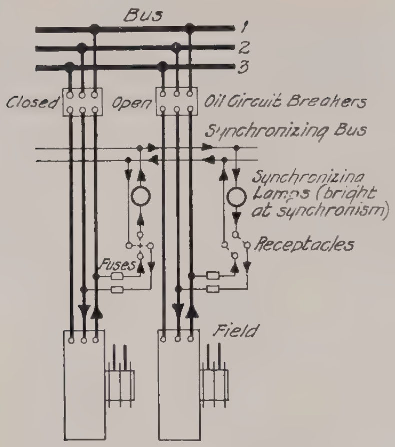


Fig. 8. Bright Lamp Synchronizing—One Lamp Per Panel

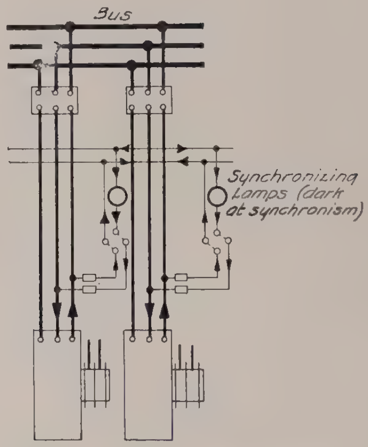


Fig. 9. Dark Lamp Synchronizing—One Lamp Per Panel

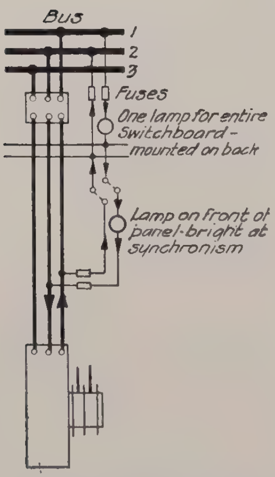

Bus
1
2
3
Fuses
One lamp for entire Switchboard - mounted on back
Lamp on front of panel - bright at synchronism

Fig. 10. Bright Lamp Synchronizing with Bus—One Lamp Per Panel

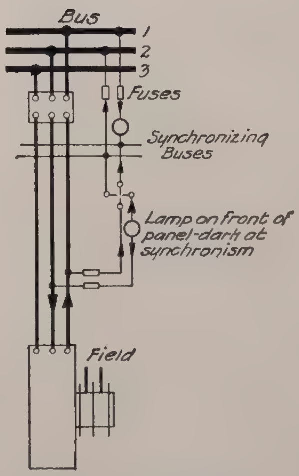


Fig. 11. Dark Lamp Synchronizing with Bus—One Lamp Per Panel

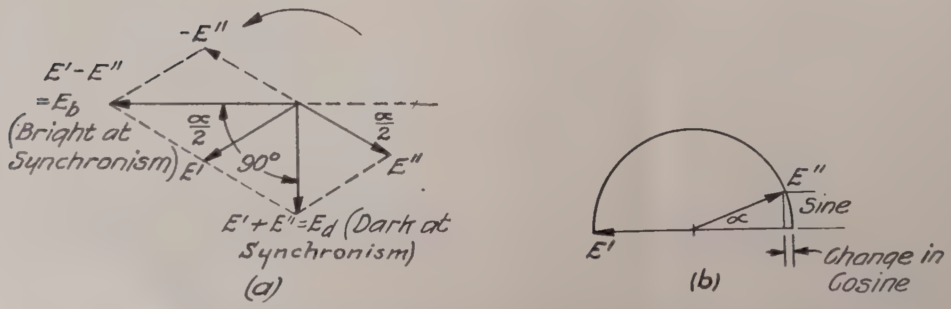

-E''
E'-E'' =E_b (Bright at Synchronism)
α/2
α/2
90°
E'
E''
E'+E''=E_d (Dark at Synchronism)
(a)
E''
Sine
α
E'
Change in Cosine
(b)

Fig. 12. The Change in Lamp Voltage is Greatest Near Synchronism with Dark Method

The objection has been raised to the dark lamp method that during the period of synchronizing, the lamp may burn out and thereby convey a false indication of synchronism. This failure, however, is not so likely to be mistaken for synchronism as might at first appear. In the first place, the filament is more likely to give out when near maximum brilliancy and no experienced operator would close the switch on such a sudden change from maximum to zero brilliancy. Even were the lamp not burned out such a rapid change would indicate far too great a difference in rotational speeds to permit the closing of the switch. In the second place, should the lamp fail somewhere near the moment of darkness, it might much more readily be mistaken for an indication of synchronism, but even were the mistake made and the switch closed no serious harm would be likely to follow as the machines if not actually in synchronism are at least then somewhere in its near neighborhood. It is highly improbable that a lamp would fail at or near synchronism as during this period the voltage impressed on it is very low; however, any fear on this score could be entirely eliminated by the use of multiple lamps, on the reasonable ground that two lamps are not likely to fail simultaneously. In the past there has been considerable controversy regarding the merits of the two methods, but with the advent of the metallic filament lamp, the trend seems to be toward the dark

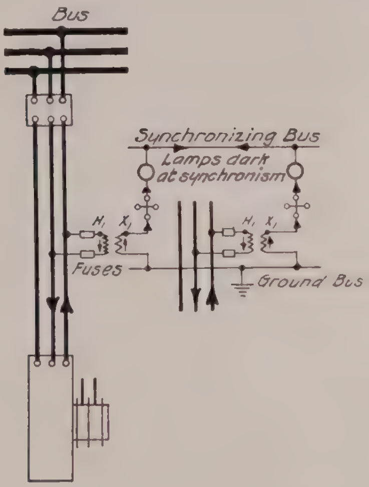


Fig. 13. Dark Lamp Synchronizing Using Potential Transformers

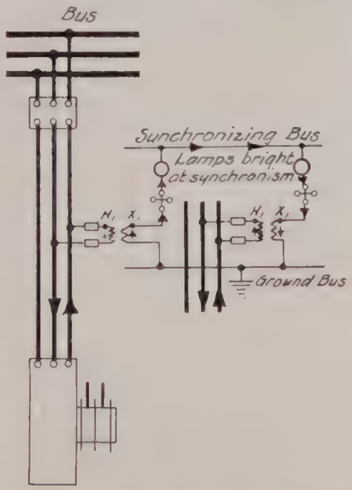


Fig. 14. Bright Lamp Synchronizing Using Potential Transformers

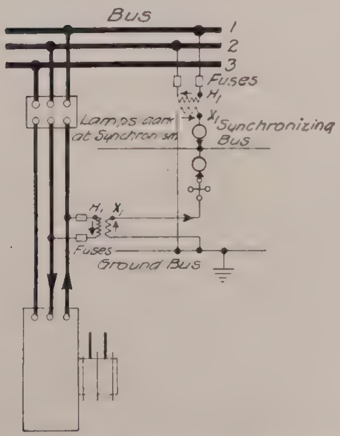


Fig. 15. Dark Lamp Synchronizing with Bus Using Potential Transformers

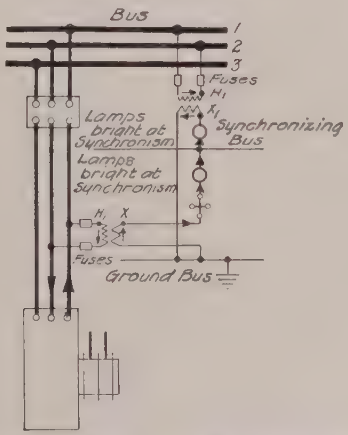


Fig. 16. Bright Lamp Synchronizing with Bus Using Potential Transformers

lamp. This is largely due to the much shorter sector over which the metallic filament is dark compared to the sector of darkness of the old carbon filament.

There are several ways, identical in principle but differing slightly in method, whereby alternating-current generators may be synchronized by means of lamps. One such method has already been shown in Figs. 8 and 10 (bright lamp) and another in Figs. 9 and 11 (dark lamp). Referring to the running machine in Figs. 8 and 10 let, at the instant chosen, line 1 be positive maximum and its current flowing towards the lamps as indicated by the arrow. Line 2 will then be maximum negative with current flowing towards the machine. When the starting machine is in synchronism with the running machine, its line 1 should also be maximum positive with current flowing toward the lamps and line 2 maximum negative with current flowing toward the machine. Following out the arrows it will be observed that at the moment of synchronism as indicated in the diagram there is a current flowing through both lamps in series, that is, the head of one arrow follows the tail of the other. This indicates that when the two machines are exactly in synchronism the sum of their two voltages is impressed across the lamps causing them to burn at maximum brilliancy.

Following the same system of arrowing in Figs. 9 and 11, however, it will be noted that at exact synchronism the arrows at the lamps are directed against each other instead of toward each other indicating that at this moment there is no voltage across the lamps and their filaments are dark.

Figs. 8, 9, 10 and 11 show synchronizing connections for comparatively low voltage generators. When the voltages are high, potential transformers are interposed between the lines and the synchronizing lamps and connections made as shown in Figs. 13, 14, 15 and 16. When using potential transformers for synchronizing great care should be exercised in ascertaining the polarity of the individual transformers. If the polarity of both transformers is the same the connections shown in Figs. 13, 14, 15 or 16 may be followed. If the polarity is not the same for both transformers then a secondary reversal must be made to take care of the difference in polarity. The polarity of a potential transformer is indicated by white marking on the correct primary and secondary leads. The white markings are supplemented by the symbol H_1 on the primary and X_1 on the secondary. These markings mean that if at any instant current flows into the marked primary lead, it will flow out from the marked secondary lead; or if at any instant current flows into the unmarked primary lead, it will flow out from the unmarked secondary lead.

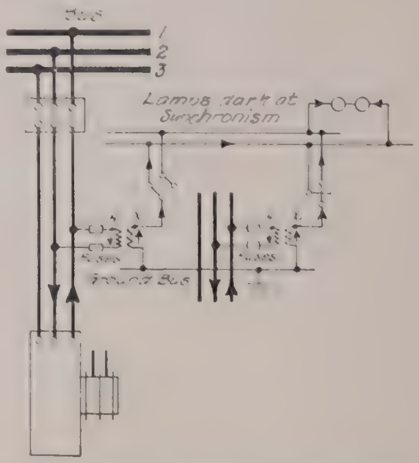


Fig. 17. Bracket Mounting for Synchronizing Between Machines—Dark Lamp Method

When it is desired to locate the synchronizing lamps on a bracket, say along with a bus voltmeter, the connections shown in Figs. 17 or 18 may be used. The arrows may be followed through exactly as described in previous methods. It should be noted that the connections shown in Fig. 18 are not suitable for more than two machines. If it is desired to parallel more than two machines with bright lamps on a bracket, the method shown in Fig. 19 may be followed. This method requires an additional potential transformer connected to the bus which, however, is entirely unnecessary when using the dark lamp method. On the whole, the dark lamp method is the simpler as far as the connections are concerned.

While the foregoing does not cover all the possible methods of synchronizing by means of lamps, it is hoped that the examples given are sufficiently numerous to enable a suitable method to be worked out for any special occasion which may arise.

Synchronizing may also be performed from the indications of a voltmeter but the principle involved is the same as that employed when using lamps, therefore a description of the method here would be largely a repetition of what has gone before. The voltmeter method is also subject to much the same objection as the lamps, on the score of accuracy. It must be able to withstand double the normal machine voltage at the moment the machines are 180 deg. displaced in phase and at the same time must, if synchronizing is performed on the principle of the dark lamp, have a very widely graduated scale in the neighborhood of zero or synchronism. In one design, Fig. 20, the instrument is equipped with a very widely graduated scale from 0 to 10 volts corresponding to the synchronous position of the machines. The remainder of the scale, from 50 up to 220 volts, being of no interest to the operator, is only about the same length as the 0 to 10 volt part. When the pointer is in the wide part of the scale a sector attached to it short circuits a resistor in series with the operating coil, but in the higher part of the scale this short circuit is broken. In other words, from zero to 10 volts the instrument is a 10-volt voltmeter while above 50 volts it is a 220-volt instrument. The device is claimed to be very sensitive and to give accurate readings when the machines are near the synchronous position.(1)

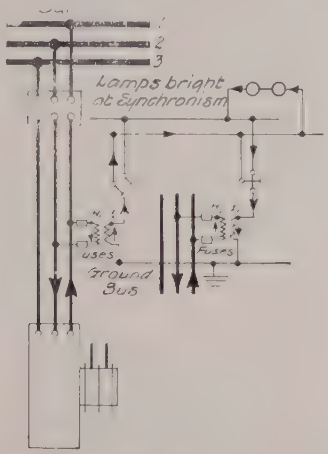


Fig. 18. Bracket Mounting for Synchronizing Between Machines—Bright Lamp Method

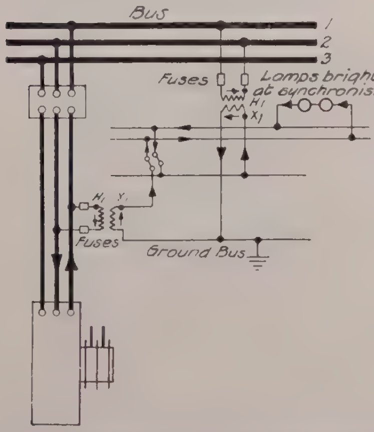


Fig. 19. Bracket Mounting for Bus Synchronizing—Bright Lamp Method

Besides inherent inaccuracy, another objection to the use of lamps or the ordinary voltmeter for synchronizing arises from the fact that as ordinarily used they give no direct indication as to whether the incoming machine is running faster or slower than the bus. This can be determined only by changing the speed of the incoming machine and noting the effect upon the rate at which the lamps flicker. If it reduces that rate an indication is given that the speed is being changed in the right direction, whereas if the rate increases it indicates that the direction of the change of speed should be reversed. To overcome this objection many schemes have been devised. In one of these, three lamps are set at the corners of an equilateral triangle, the direction of rotation of the order of brilliancy around the triangle giving a direct indication of the relative speed of the incoming machine.

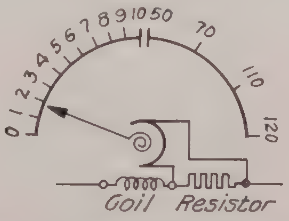


Fig. 20. Special Voltmeter Designed for Synchronizing on Low-voltage Scale

Electrostatic Synchroscope

This method of determining the instant of phase coincidence utilizes the instantaneous difference of electrostatic potential on high-voltage transmission lines to cause a visible discharge across the electrodes of a specially prepared bulb. As the luminosity is necessarily low, the value of the method is enhanced by locating the bulbs or glowers in a partially darkened room. It is particularly adapted for use at remote tie points on high-voltage transmission systems—where the infrequent occasions on which synchronizing has to be performed do not warrant the expense of a rotary instrument with its accompanying potential transformers; and where the impedance of the transmission system to the tie point is sufficient to cushion the effect of an occasional poor shot. There is no contention, however, regarding its inferiority to the rotary type equipment in every respect except that of first cost. Furthermore, special consideration must be given to the arrangement of the devices comprising the outfit so that maximum charge may be maintained on the lead-in wires up to the glowers.

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(1) For a more complete description of this device, see *Elektrotechnische Zeitschrift*, Vol. 44, No. 46.

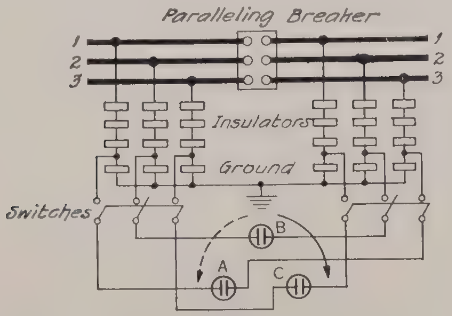

Fig. 21. Method of Connecting Electrostatic Synchroscope

The necessary apparatus and connections are shown in Fig. 21. It will be observed that while the upper bulb is connected to the same phase on both sides of the switch, the connections to the two lower bulbs are made across opposite leads, that is, the right hand bulb is connected to lead 3 on the left side of the paralleling switch, and to lead 1 on the right side. This is done in order to obtain the voltages shown in Fig. 22.

Considering Fig. 22 (a) it is clear that at synchronism bulb *B* is dark while bulbs *A* and *C* are glowing at 86.6 per cent maximum. When the system indicated by the primes has gained 60 deg. on the slower system as shown in Fig. 22 (b) lamp or glower *B* has begun to glow at 50 per cent of maximum, glower *A* has *increased* to maximum brilliancy, while glower *C* has *diminished* to 50 per cent of maximum. As the faster system continues to increase its lead to 120 deg. lamp *C* becomes dark and lamps *A* and *B* glow at 86.6 per cent of maximum. At this point the systems are 120 deg. displaced in phase, as shown in Fig. 22 (c). A further increase of 60 deg. is shown in Fig. 22 (d) bringing lamp *B* to maximum brilliancy and lamps *A* and *C* to 50 per cent of maximum.

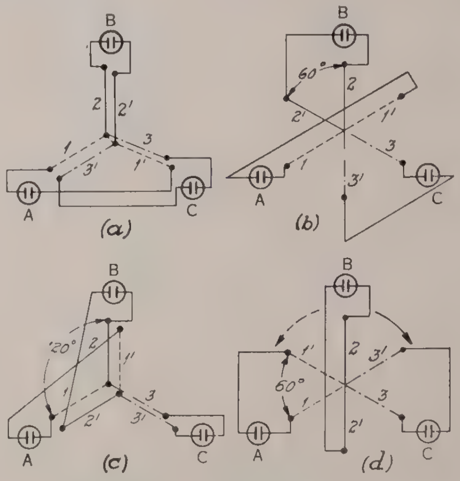

Fig. 22. Showing How Rotational Effect is Produced on the Electrostatic Synchroscope

Continuing the vectors around another 120 deg. it will be found that lamp *C* has come to maximum brilliancy while *A* and *B* are at 50 per cent of maximum. It is evident, therefore, that if the three lamps are set at the corners of the equilateral triangle shown in Fig. 21 they will reach maximum brilliancy in the order *A-B-C* when the system denoted by the primes is the *faster*. This would result in an apparent rotation round the triangle in the direction indicated by the dotted arrow. The speed of the rotation is obviously a function of the difference of the speeds of the two systems. Conversely if the speed of the system denoted by the primes is less than the speed of the other system, the sequence of brilliancy around the triangle would be in the direction indicated by the arrow shown in full, the speed, as before, being proportional to the difference in the system speeds.

(To be continued)

Automatic Starting of Synchronous Motors

By R. M. Matson and R. E. R. Parry

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Constant improvements in the design of the synchronous motor have gradually widened its sphere of application until today the benefits of a synchronous motor drive are available wherever constant speed motive power is required. The increasing application of this type of motor has called for refinements in the method of starting, so that automatic starters are built that are rugged, inexpensive, and foolproof. In addition, they afford protection to the motor from sources of possible damage, such as overload, single-phase operation and failure of excitation A few years ago it required a certain amount of skill to start a synchronous motor properly; today it is only necessary to press a button.—Editor.

Since the advantages of operation at good power-factor are becoming more fully appreciated by industrial engineers, the number of synchronous motor drives is rapidly increasing, particularly in connection with compressors, centrifugal pumps, jordans in paper mills, rubber mill roll drives, etc.

For such purposes synchronous motors of a new design⁽¹⁾ have been developed in a variety of sizes and for low, medium, and high-speed drives. All these new machines are so designed that they draw low starting current, give high efficiency, and require low excitation, and yet have a uniform accelerating torque. As a result the motors of the same horse power rating are smaller than before, and require smaller exciters.

The low-speed type of motor has been so designed that it can be thrown directly across the line on starting; while the medium and high-speed machines still require reduced voltage starting.

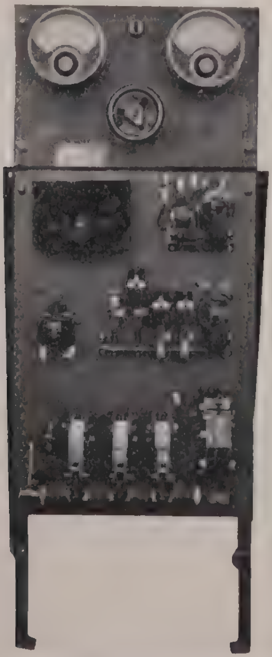

Fig. 1. Automatic Starting Panel for Low-speed Synchronous Motor

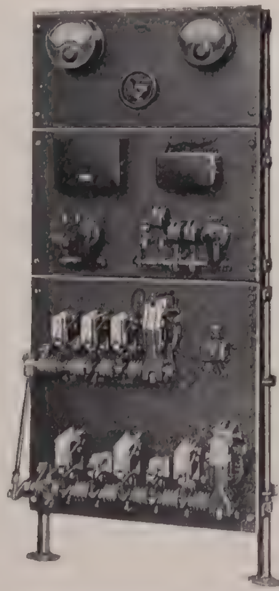

Fig. 2. Automatic Starting Panel for High-speed Synchronous Motor

The increased demand for synchronous motors has necessarily caused a corresponding demand for a simple and reliable type of automatic starter. No part of the starting procedure is then left to the judgment of the operator, who need not be particularly skilled in starting motors.

Therefore, to avoid the possibility of abusing the motor, due to carelessness, and to

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(1) Identified by the trade designation "Type TS."

insure uniformly rapid starting, two new types of starting apparatus have been designed. For the low-speed motor there is an across-the-line starter, shown in Fig. 1, and for high-speed motors there is a reduced voltage starter, shown in Fig. 2.

In one respect a synchronous motor corresponds to the squirrel-cage induction motor; i.e., during the starting period the amortisseur winding of a synchronous motor serves the purpose of the squirrel cage winding of an induction motor and produces a starting torque in a similar manner. The synchronous motor requires an additional step to complete the starting operation—the application of d-c. excitation to the motor field. It can therefore be seen that the starting of a synchronous motor is similar to that of an induction motor, the only complication involved being the application of field to the motor at the proper time.

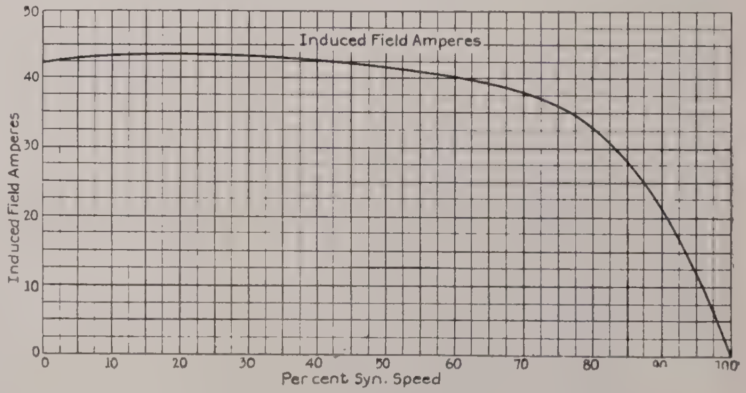


Fig. 3. Showing Variation of Induced Field Current with the Speed

If, when voltage is applied to the terminals of a synchronous motor, the field circuit is closed through a discharge resistor, an alternating voltage is induced in the field windings of the motor. When the motor is at rest, this induced voltage has a frequency corresponding to the line frequency. As the motor accelerates this frequency decreases, and becomes zero when the motor reaches synchronous speed. The induced voltage also decreases as the motor accelerates, and the combination of decreasing frequency and voltage gives practically a constant induced field current (Fig. 3) until the motor approaches synchronism. Therefore field can be applied by relays responding to decreasing frequency and by relays responding to decreasing induced field current. Field may also be applied by a time element method which functions independently of the speed of the motor.

One form of frequency relay consists of an armature actuated by a relay coil of high resistance and low inductance wired in parallel with a reactance coil of low resistance and high inductance. When voltage is applied to the motor, current is induced in the motor field which causes the frequency relay to pick up, due to the high impedance of the reactance coil diverting most of the current through the winding on the frequency relay. As the motor accelerates, the frequency of the induced field voltage drops, allowing the current to flow through the reactance coil, causing the frequency relay to drop out, which in turn allows field current to be applied.

A time-element relay functions independently of the speed of the motor, so that it is possible to set the predetermined time interval, before applying field current, at a value which is sufficient to allow the motor to accelerate to its highest speed under all conditions.

One form of "induced field" relay has two pairs of contacts; one a make contact, the other a break contact. It also has two electromagnets; one operates on direct current and is connected to the source of excitation, the other one operates on alternating current and is connected to the field circuit during starting. As the motor accelerates, the current in the a-c. winding of the relay decreases until the d-c. winding exerts a greater force, causing the relay to operate.

Another form of field relay, the one used in the starters shown in Figs. 1 and 2, is shown in Fig. 4, and responds to a diminishing induced field current. It consists of a contactor armature on which is mounted a magnetic time interlock. At the time the contactor coil is energized the interlock tends to close, but is prevented by a retarding coil which is in series with the motor field, and energized by the current induced in the field winding. As the motor accelerates the induced field current decreases, as shown in Fig. 3.

The relay is so designed that it releases as the motor approaches synchronism, allowing the interlock to close, and after a brief delay, applies full field. This delay allows the relay to be set to release at the highest speed to which the motor will accelerate under the worst conditions, but yet allows a time delay in applying field so that under normal conditions the motor will reach a still higher speed before field is applied.

The across-the-line starter, Fig. 1, consists essentially of a line contactor, a field relay, a field contactor, a field protective relay, a temperature overload relay, a rheostat operating mechanism which may be used to operate a chain rheostat or rear-mounted rheostat, a line ammeter, a field ammeter, and a pilot light for indicating line voltage.

Fig. 5 shows a simplified connection diagram of an across-the-line starter. Pushing the start button energizes the line contactor coil (*LE*), closing the line contactor and connecting *L1*, *L2*, and *L3* to the motor. The interlock *LE* closes at the same time as the line contactor and forms a holding circuit for the line contactor, so that the push button may be released. While the motor is accelerating the field circuit is closed through the normally closed pole (*F3*) of the field contactor, through the discharge resistor and the retarding coil (*FR*) of the field relay. This holds the interlock (*FR*) open until the motor approaches synchronism. At the time the line contactor (*LE*) closes, the contactor coil (*FR*) is energized and tends to close the interlock (*FR*). As the motor accelerates, the induced field current through the retarding coil (*FR*) decreases, as shown by Fig. 3, and releases the interlock (*FR*) when the motor nears synchronism. After a few seconds' delay the interlock (*FR*) closes, energizing the contactor coil (*F*), causing *F1* and *F2* to close and *F3* and *F4* to open. The closing of *F1* and *F2* applies excitation to the motor field, completing the starting operation. The opening of *F3* opens the discharge circuit of the motor field. The opening of *F4* allows *FP* to shut down the equipment in case of failure of voltage on the exciter bus. *FP* must have closed its contacts before the field contactor opens *F4*, necessitating that excitation voltage be available before attempting to apply field.

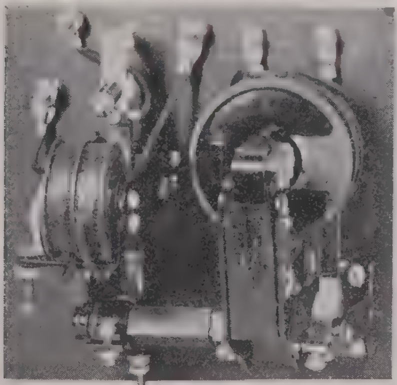


Fig. 4. Relay Whose Operation is Dependent on the Induced Field Current

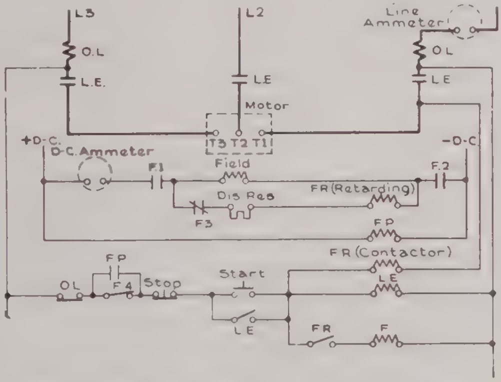


Fig. 5. Simplified Diagram of an "Across-the-Line" Starter

The reduced voltage starter, Fig. 2, is similar to the starter just described with the addition of a starting contactor for connecting the auto-transformer to the motor and to the line, and an induction time relay for changing from starting to running connections. In this case pushing the start button energizes the accelerating contactor which connects the auto-transformer to the line and to the motor. Simultaneously the induction time relay is energized. After a time interval corresponding to the setting of this timing relay the accelerating contactor opens, disconnecting the auto-transformer from both the line and the motor. The line contactor is closed immediately, connecting the motor directly to the line. After this the operation of the panel is the same in its operation as the across-the-line starter.

The main conditions to guard against during starting and running a synchronous motor are:

(1) Overload on the motor.

(2) Overheating of the amortisseur winding.

(3) Loss of excitation.

(4) Single-phase operation.

This protection is provided on the reduced and full voltage starters, shown in Figs. 1 and 2, in the following manner:

The motor is protected from overload by means of a temperature overload relay. This relay is of the polyphase type, hand reset, and provides protection based on the heating characteristics of the motor. This relay will give the maximum protection with the minimum number of shutdowns by operating just before the motor windings become heated to a dangerous temperature. This relay (*OL*) is connected in the circuit at all times, as shown in Fig. 5.

The amortisseur winding of a synchronous motor is so designed that it will not overheat during the average starting period. The overload relay, being in the circuit during the starting period and based on the normal heating of the motor, will operate and disconnect the motor from the line in the event of an unusually long starting period, before the amortisseur winding or motor overheats.

Loss of excitation permits the motor to drop out of synchronism, temporarily drawing an objectionable overload current from the line. The most common cause of failure of excitation is the loss of the source of supply for the exciter bus, such as caused by the breaking of a belt on a belt-driven exciter. On these starters, the small protective relay, shown by (*FP*) Fig. 5, guards against operation of the motor without exciter voltage.

A motor operating on single phase draws a large current in that phase. This corresponds to an overload on the motor and is taken care of by the overload relay.

Fig. 6 is a pictorial representation of an across-the-line starter, showing its connections and relations to a synchronous motor and exciter.

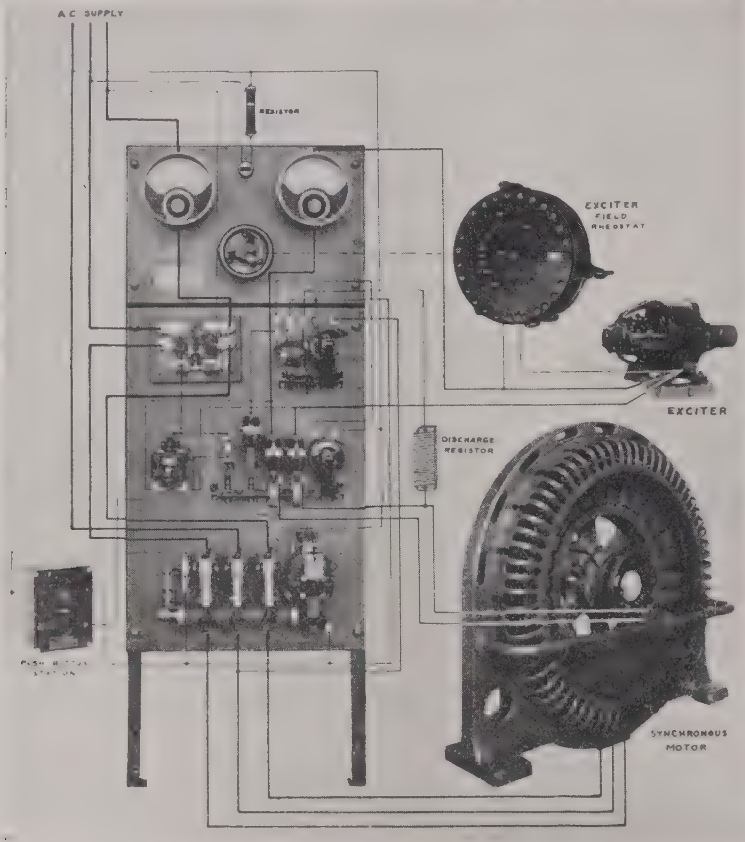


Fig. 6. Pictorial Representation of an "Across-the-Line" Starter

Notes on Light and Vision

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

The extremely delicate construction of the human eye and the comparatively rugged features of the ear might lead one to believe that the eye must be more responsive to light than the ear is to sound. In this article the author shows that the reverse is true for the range of responsivity of the average human ear is approximately ten times greater than that of the eye. In the addition of colors, red and yellow, the eye perceives orange, but who will allow that the notes A and C on the piano when struck together sound as B. The author next presents a careful analysis of some types of glare and other causes of eye fatigue. In closing there is a brief discussion of the merits of the three forms of lighting—direct, indirect and semi-indirect.—Editor.

The known principles of light and lighting are so intimately connected with the phenomena of the human eye that in nearly every case where we have an unusual or difficult problem in lighting, the real difficulty is found to arise from some peculiarity of the eye. Our problems in applied light are really questions concerning vision and we often find the answer in the psychology of vision. It is not the intention here to attempt to analyze the psychology of the subject, or to enter much into the physics of light or the mechanical details of lighting, but rather to confine attention to a few of the more prominent relations between light and vision.

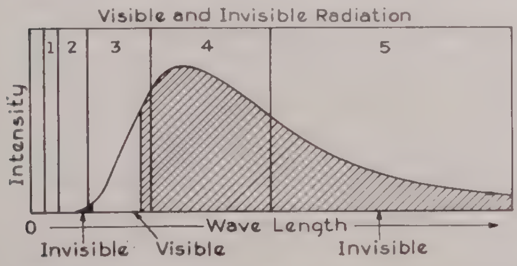


Fig. 1. Radiation from a Body at a Temperature of 2800 deg. Abs. (C.) Arbitrarily Divided Into Octaves. The most efficient light source is the one having the peak of the emission curve near the center of the region shown as Octave 3

The eye as an optical instrument alternately excites our admiration by its perfection in some respects and causes us regret by its shortcomings in others. These imperfections are often perhaps more imaginary than real, but even if imaginary, they certainly add greatly to the difficulty of producing satisfactory illumination. Among the things that we might call an optical shortcoming is the limited range of sensitivity of the eye. The sensation of light is caused by vibrations in the ether striking the eye much in the same manner as the sensation of sound is caused by vibrations in the air striking the ear. We may receive the sensation of sound from sixteen vibrations per second and also from 20,000 vibrations per second. These limits vary for different people but in general our hearing is sensitive to more than eleven octaves. A piano has over seven octaves and the ear is decidedly sensitive to the whole range of notes. Moreover, the notes in any octave seem to have nearly equal effect upon our hearing, that is, any one note has about the same intensity as those near it. The eye is sensitive to less than a single octave, and the vibrations near the ends of the octave are very much less effective in producing vision. It is exactly as if we were deaf to all but one octave on the piano, and the ear with difficulty heard the first and last notes.

This limitation gives rise to the first great problem in practical lighting. The light source as far as possible must concentrate its vibrations to this single octave within which the eye is effective. The action of certain vibrations outside of this octave are injurious and even destructive to the tissues of the eye. These vibrations are all the more dangerous because we have no sense of danger until harm is done. We have thus a double reason for trying to keep the radiations from our light source within very definite limits. A glance at Fig. 1 in which the effective vibrations are represented by the white space under the curve, and the wasted vibrations by the shaded area, shows that the useful energy is only a small part of the total. The recent rapid advances in lighting are largely due to methods that enable us to get a greater proportion of the energy in the effective octave.

There is a second characteristic of the eye that presents a nice problem to the illuminating engineer and causes endless complications. This characteristic is the adding-up action or the lack of a keen analyzing power for colors. Here again we may compare the ear and eye much to the advantage of the former. We may match the seven colors in the spectrum, red, orange, yellow, green, blue, indigo, violet, with the seven whole tones in the octave of music. If vibrations near one end of the light octave strike the eye, we receive the sensation we call red. If A on the music scale is struck, the ear transmutes the air vibrations into sensation and we recognize the note A. If both A and C are struck, our ears correctly inform us that two notes, A and C, were sounded. Let us now mix two rays of light, one red, the other yellow, corresponding to the two notes A and C. The eye does not inform us that we see red plus yellow but it says the single color orange. The eye cannot in any way distinguish this orange light, which contains no vibrations of orange frequency, from orange light that contains neither red nor yellow but is a pure spectrum orange. Our ears would never deceive us into thinking that the two notes A and C were a single note B. It is an interesting speculation to consider what the result would be on music if our ears decided to imitate our eyes and give only an average result when a group of keys were struck. The most complicated music would shrink into the equivalent of a one-finger tune picked off "by ear," while Chopin and Jazz would be drab twins.

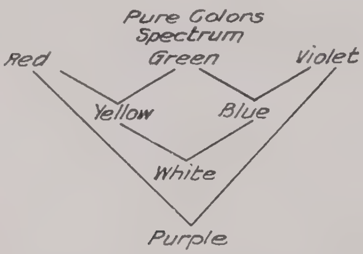


Fig. 2. The Primary Colors and Their Mixtures as Arranged by the Physicist Who Deals in Pure Colors

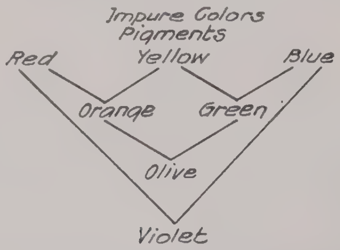


Fig. 3. The Primary Colors and Their Mixtures as Arranged by Color Workers Using Pigments That Reflect a Mixture of All Colors

There are endless assortments of pure spectrum colors that may be combined to form what is apparently a third pure color. The classical example of the analyzing limitations of the eye is found in the combination of all the colors of the spectrum into white. White, according to accepted usage, is not a color, but lack of color, yet it is always made up of two or more colors.

The pure colors of the spectrum are divided into the three so-called primary colors, red, green and violet, and the secondary colors, yellow, blue and purple. The combination yellow plus the combination blue will give the sensation of white light. Also, pure spectrum yellow plus pure spectrum blue will give white, so that white may contain two or four colors. As a matter of fact, white may be made of any number of colors we please, providing we can do the mixing properly. In white light made from red and green, green and violet, the colors orange and blue are missing, but the eye does not detect the fact. Or, we take a spectrum yellow and a spectrum blue, and get white light without in the least detecting the absence of red, green and violet.

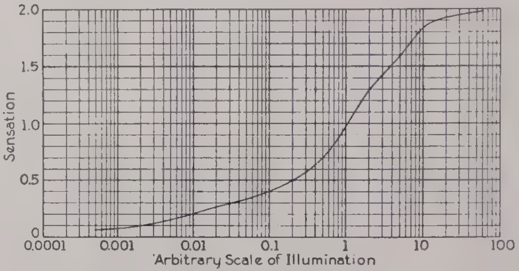


Fig. 4. The Sensation of Brightness Under Natural Night Intensities is Illustrated by the Left Section of the Curve. When daylight intensities are encountered the sensation rises at a more rapid rate until the region of glare is entire at which time the rise of sensation proceeds slowly

In our schools we teach a color system that seems to be radically different from the scheme outlined above. The difference arises from the fact that in physics and lighting we deal in the pure colors of the spectrum, while the series of pigment colors are apparent and not real colors. The public school system of color instruction is carried on with the aid of colored paper, fabrics and crayons. These articles of course do not generate light. They can only reflect part of the light that falls upon them so that what we call the color of an object is really a measure of that object's ability to reflect certain colors. If those colors are not present in the light before it strikes the object they evidently cannot be there after reflection. Colored surfaces that do not reflect some part of all the colors of the spectrum are rare. Thus a red book cover reflects red and orange readily, yellow less readily, and green, indigo and violet weakly, but still to a great enough extent to make the entire spectrum discernible on analysis. In this impurity of the reflection spectrum is found one reason for the different systems of primary colors mentioned.

If the binding of a book reflects red and green light about equally well and the other colors only very slightly we call the binding of the book yellow, providing there is both red and green light in the light falling upon it. If the light is weak in red then the binding appears to be of some color between yellow and green. If the green component of the light is weak then the book seems to be orange or scarlet. If the binding looks yellow to us under a certain illuminant, we cannot say with certainty that it is yellow until we know something about the composition of the light by which we see it. We can only say that under that light it appears yellow. If the "yellow" book cover actually reflected no yellow and we illuminated it by pure spectrum yellow the book would appear black. The color of an object is thus not a constant, invariable thing, but depends upon the source of illumination.

The so-called primary colors we get in paints and crayons are of an indefinite color and, under different light, may appear to be different tones of the same color or even a totally different color. The pigment primaries are red, yellow and blue. The mixture of red and yellow gives orange. This agrees with the mixture of spectrum colors. The mixture of yellow and blue pigments does not make white, however, but green. This is at variance with what we might expect but the explanation is simple enough. Our eyes do not detect the presence of a green impurity in the yellow pigment. Likewise there is a green impurity in the blue that we cannot see. Then the yellow and blue are mixed, the yellow and blue cancel one another and the only thing left is the green impurity that is common to both. This impurity of color, which is encountered in every pigment and dye, gives rise to one of the requirements of good lighting that has lately come into considerable prominence in the illuminating engineering profession.

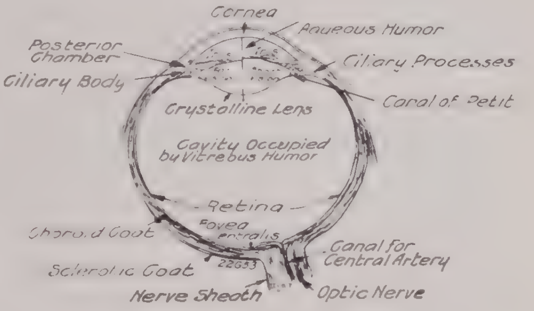


Fig. 5. The Crystalline Lens is Shown with the Curvature it Takes for Far and Near Vision

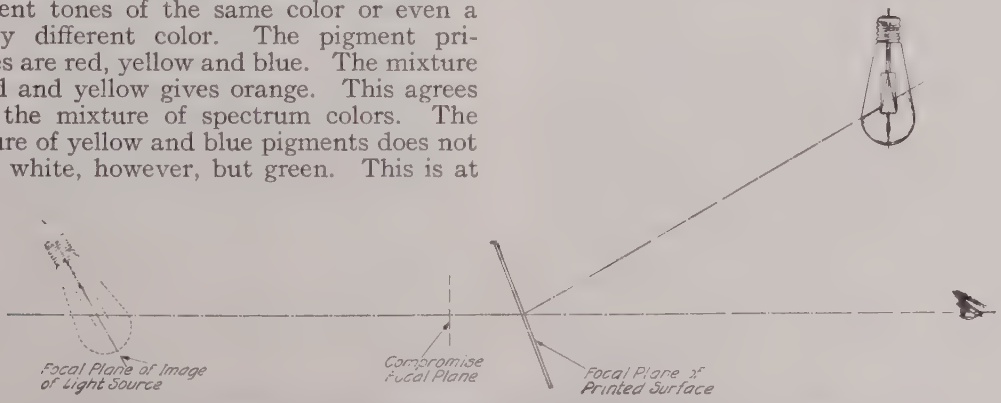

Focal Plane of Image of Light Source
Compromise Focal Plane
Focal Plane of Printed Surface

Fig. 6. A Diagram Showing the Position of the Reading Surface, the Lamp Image, and the Compromise Focal Plane, Giving the Results Illustrated in Figs. 7, 8, and 9

The yellow crayon may change to a yellow-green, if the source of illumination has an excess of green rays. Doubling the proportion of green light in the source would have much the same visual result as doubling the green impurities in the crayon. If we are to standardize our colors we must also standardize our lights. If we learn a series of colors under carbon filament incandescent lamps which give a very yellow light and then try to identify them under a blue sky we might have some difficulty, and the difficulty would be greater the better our color memory is. An artist sketching in the open would like to feel certain that when he viewed his sketch at night the colors would be true. In buying goods that should match, we are often surprised to find that a pleasing match under the artificial light of the store is a serious clash in daylight. The obvious remedy is to have daylight and our evening light of not only the same apparent color, but actually be the same throughout the spectrum. When artificial lighting has progressed to this stage, our eyes will cease to deceive us, at any rate they will deceive us uniformly under all light.

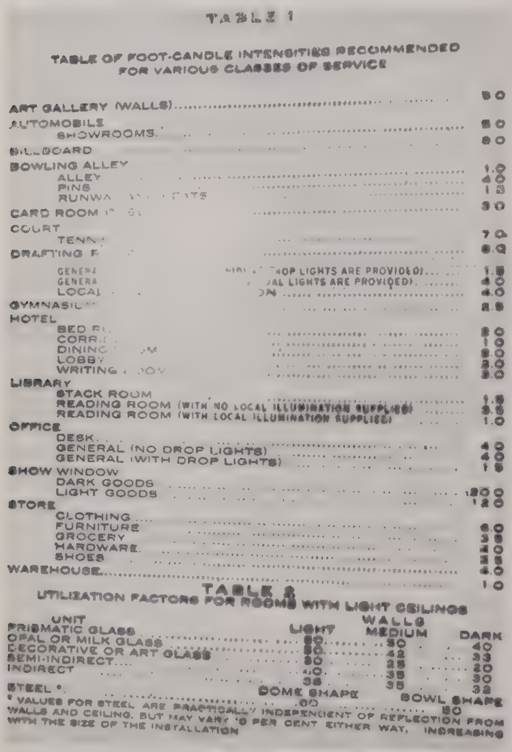


TABLE 1

TABLE OF FOOT-CANDLE INTENSITIES RECOMMENDED FOR VARIOUS CLASSES OF SERVICE

5 0
ART GALLERY (WALLS)
AUTOMOBILS 5 0
SHOWROOMS 8 0
BILLBOARD
BOWLING ALLEY 1.0
ALLEY 4 0
PINS 1 5
RUNWA
3 0
CARD ROOM
COURT
TENN 7 0
DRAFTING R 8.0
GENER DROP LIGHTS ARE PROVIDED) 1.5
GENERA AL LIGHTS ARE PROVIDED) 4 0
LOCAL ON 4.0
GYMNASIU 2.5
HOTEL
BED R 2 0
CORR 1 0
DINING M 2.0
LOBBY 2.0
WRITING OM 3.0
LIBRARY
STACK ROOM 1.5
READING ROOM (WITH NO LOCAL ILLUMINATION SUPPLIED) 3.5
READING ROOM (WITH LOCAL ILLUMINATION SUPPLIED) 1.0
OFFICE
DESK
GENERAL (NO DROP LIGHTS) 4 0
GENERAL (WITH DROP LIGHTS) 4 0
SHOW WINDOW 1 5
DARK GOODS
LIGHT GOODS 200
STORE 120
CLOTHING
FURNITURE 6.0
GROCERY 3 5
HARDWARE 4 0
SHOES 3 5
WAREHOUSE 4.0
1 0

TABLE 2

UTILIZATION FACTORS FOR ROOMS WITH LIGHT CEILINGS

UNIT WALLS
PRISMATIC GLASS LIGHT MEDIUM DARK
OPAL OR MILK GLASS 50 50 40
DECORATIVE OR ART GLASS 50 42 33
SEMI-INDIRECT 30 25 20
INDIRECT 40 35 30
38 35 32
STEEL * DOME SHAPE BOWL SHAPE
* VALUES FOR STEEL ARE PRACTICALLY INDEPENDENT OF REFLECTION FROM .60 50
WALLS AND CEILING, BUT MAY VARY 10 PER CENT EITHER WAY, INCREASING
WITH THE SIZE OF THE INSTALLATION

Fig. 7. With the Eyes Focused on the Surface of a Glossy Card, All Reading Matter Not Directly in Line with the Image of the Lamp is Clear in Outline

There is no field of experience in which our judgment is weaker and more liable to err than in our estimates of light intensities. We have seen that our sense of color may lead us into various mistaken impressions and, in like manner, our sense of brightness is most untrustworthy. As an example, let us consider the intensities on a desk during the day and at night under artificial light. On a bright day we may work in comfort under an illumination twenty times as great as we require at night. Our eyes seem to act with equal comfort in both cases, and as far as our sense of brightness can inform us, the two illuminations are equal. Anyone who has tried to increase the illumination of a bright room in the daytime by turning on the electric light knows how feeble the light from the latter seems to be.

The manner in which we judge intensities is illustrated by the curve in Fig. 4. This curve is for green light only, but the shape is typical for all the colors and white light. The details of this curve lead us into physiology and psychology. The thing to be noted is that, in general, if we wish to double the apparent brightness of an object we must have about ten times the light. Near the middle of the curve there is a sharp turn upward. This turn is supposed to mark the beginning of vision by means of the cones of the retina. Below the turn the rods act alone and above it the rods and cones are both active. The range of intensities covered by this curve is 100,000 to 1, while the sensation changes are in the ratio of 30 to 1.

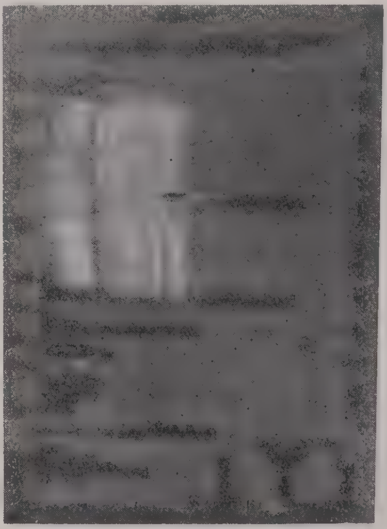


Fig. 8. When the Eyes Focus on the Image Seen in the Card, the Remainder of the Surface Becomes Blurred and Dark and the Print is Barely Seen

It is an interesting fact that at both extremely high and extremely low intensities the eye loses its color sense entirely and all colors appear white.

The boundaries of ordinary indoor artificial lighting are very much closer together. For our homes and offices the usual limits are between one foot-candle and ten foot-candles, so that the range of brightness one ordinarily requires for working or reading is, on the sensation scale, only from one to two.

The eye is not an optical instrument that can operate indefinitely under all conditions. It is subject to discomfort, fatigues, and pains, and the problem of supplying the eye with light, so that is can operate for long periods with accuracy and comfort, is essentially the problem on which every illuminating engineer is working. We have considered the effects of colors and intensities, but these are really the simpler factors. The things that are difficult are not supplying quantity and quality, but in so supplying the light that the psychological needs are satisfied. These needs we usually speak of as comfort, pleasant impressions and clearness of vision.

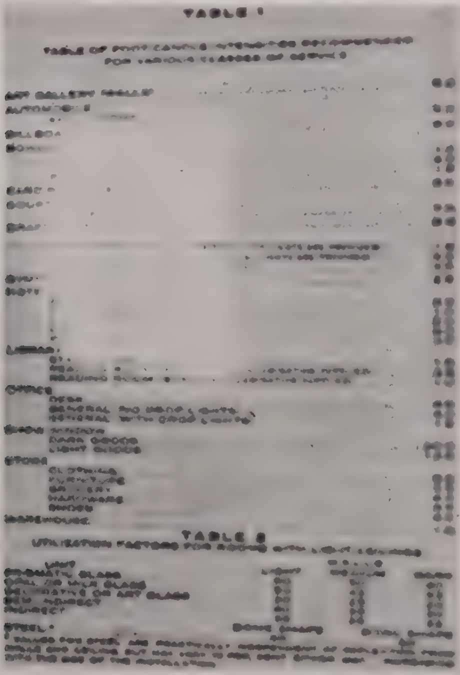


Fig. 9. After a Short Time of Reading the Eye Muscles Fatigue and Fail to Hold the Lenses and Optical Axes in Proper Adjustment with the Compromise Result Shown

Before taking up the subject of eye comfort and some of the principles of lighting that are involved in good lighting practice, let us glance for a moment at the mechanism of the eye itself. The part that we are particularly interested in is the lens arrangement that brings the light entering the eye into focus upon the retina or sensitive coating on the back wall of the eye. We are all familiar with the method of bringing an opera glass or telescope into focus. The distance between the front and rear lenses is changed by turning a screw or otherwise altering the length of the instrument. The eye has no means of altering its depth from front to back, but it accomplishes the same result by altering the shape of the crystalline lens. The right side of crystalline lens, in Fig. 5, is shown in the shape it takes for objects nearby. For seeing distant objects the lens is thinner as shown on the left-hand side of the diagram. As we walk along the street or glance about the room, the crystalline lens is in constant motion changing its shape to correspond to the distance. This action is entirely automatic and does not require our attention. If for any reason the lens does not respond promptly to the need of the moment, we cannot see clearly and things look indistinct and blurred. This condition is extremely trying on both the physical and mental system, and anything that leads to it should be carefully avoided.

The strain under which the eye can be placed by a lack of satisfactory focus may be shown in several ways. One of the simplest ways is to consider what happens when we read a book or paper that gives bright spots and lines of reflected light. This is what we call glare—the example of glare given below is perhaps an extreme case, but it serves the purpose of illustration all the better.

A shiny celluloid card was held so that there was a bright spot of reflected light near the center. This light was direct reflection from a lamp placed as shown in Fig. 6. In order to read the printed matter, it was, of course, necessary to focus the eyes on the plane of the card, which appeared as shown in Fig. 7. As the line of vision approached the bright spot, the eye was involuntarily brought into focus for the image of the lamp since this was much brighter than the printed surface. The image now became better defined, as in Fig. 8, while the printed matter became merely gray spots and streaks. In order to continue reading, the eye had to be brought back into focus at the surface of the card and this required considerable effort. Any relaxation of attention and the eye immediately focused again upon the image. It was only by continued effort that the eye could be kept adjusted for reading.

There was a strong sense of strain and a very annoying uncertainty as to the proper focal point. While the reading in and near the glare spot was going on the eyes seemed to be constantly hunting for the proper adjustment and always failing to find it. The result was that the eyes kept focused on a point between the card and the image back of it, giving the card the appearance, somewhat, as shown in Fig. 9.

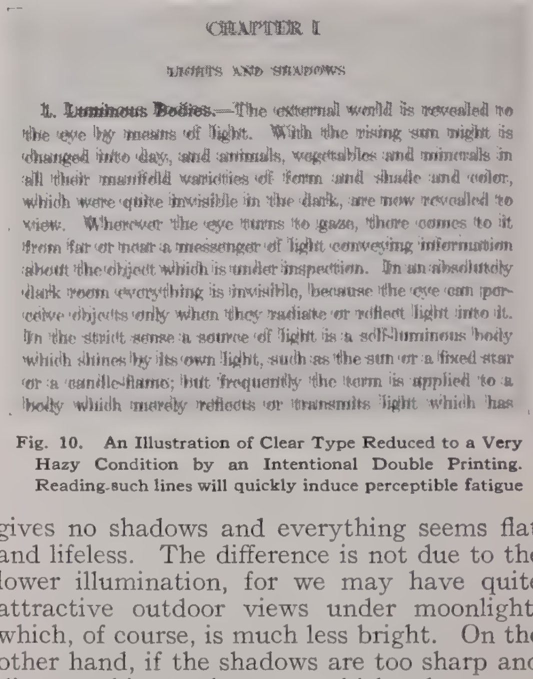
The same effect may be seen on the polished top of a table or desk. A glance at the glare spot shows a single image, but if we place a small object such as a pencil at the glare spot and fix our attention upon it we are immediately conscious of two images, one for each eye, showing that the axes of the eyes converge on the desk and not on the image as before. A glare spot near the edge of the paper on which we are working distracts our attention and for the time being lowers our efficiency. It may often happen that we are not conscious of the reason for our feeling annoyed and uncomfortable until the accumulated effects of the strains produce serious eye trouble.

It would thus seem as if the principles of lighting should be extended to cover not only the arrangement and character of natural and artificial light, but should include the type of paper used for books and all other printed matter, and also the polish on desks and tables.

There is a common phenomenon that is closely akin to the above example of glare strain, but it does not involve high intensities, indefinite focal planes or great contrasts of brightness. Occasionally, we see a poorly printed newspaper in which the type is double-printed. There is a fairly heavy impression of clear letters, and slightly offset, a second printing of fainter letters. Here are two sets of letters each legible and each occupying a very definite reading plane. As an example of geometrical optics it is difficult to see why the double printing should do more than slightly lower our speed of reading, but from actual experience we know that reading even a few lines of this print produces eye fatigue and long reading invites disaster. The fatigue here is occasioned by the focusing mechanism of the eyes attempting the impossible. The rotating muscles and focusing muscles automatically adjust the eyes so that the object of vision appears in the sharpest possible outline. These muscles try to adjust the eyes to unite the two impressions and they never give up trying so long as the reading continues. Here there is a constant adjustment and readjustment, seeking the unattainable, until from sheer fatigue we give up the attempt to read.

These two examples indicate that "glare" is a little more complicated than a question of brightness and place in the field of vision, and that muscular fatigue is a prime element of glare strains.

We distinguish objects in the field of vision not so much by the light we receive from them as by differences in brightness and color and by contrast with the background. A ball equally illuminated on all sides appears not spherical but flat. We have difficulty in telling the distance to a newly plastered wall, not because it lacks brightness, but because there is no point of shade or color to engage and fix the attention. Shadows and variations in illumination are very desirable features. A bright sunshiny day is pleasant largely because there are plenty of shadows and variations in brightness. An overcast sky gives no shadows and everything seems flat and lifeless. The difference is not due to the lower illumination, for we may have quite attractive outdoor views under moonlight, which, of course, is much less bright. On the other hand, if the shadows are too sharp and distant, things take on a cold harsh appearance.



CHAPTER I

LIGHTS AND SHADOWS

1. Luminous Bodies.—The external world is revealed to the eye by means of light. With the rising sun night is changed into day, and animals, vegetables and minerals in all their manifold varieties of form and shade and color, which were quite invisible in the dark, are now revealed to view. Wherever the eye turns to gaze, there comes to it from far or near a messenger of light conveying information about the object which is under inspection. In an absolutely dark room everything is invisible, because the eye can perceive objects only when they radiate or reflect light into it. In the strict sense a source of light is a self-luminous body which shines by its own light, such as the sun or a fixed star or a candle-flame; but frequently the term is applied to a body which merely reflects or transmits light which has

Fig. 10. An Illustration of Clear Type Reduced to a Very Hazy Condition by an Intentional Double Printing. Reading such lines will quickly induce perceptible fatigue

In outdoor lighting the shadow principle holds true. In the early days of lighting it was common practice to have the light source bare and quite near the place to be illuminated. With only one or two lights in a room the shadows were black and sharp edged. The warmth of the usual yellow or orange light was offset by the cold and uninviting appearance of the shadows. The trouble once being located, steps were taken to rectify it by diffusing the light and paying more attention to the location of the lamps. Among other schemes used was the totally indirect system in which all the light from the lamps was thrown on the walls and ceiling and from these reflected to the floor.

The object of totally indirect systems is to diffuse the light so as to eliminate shadows and glare. It succeeds in preventing shadows but cannot absolutely prevent glare, as that depends largely upon the reflecting surfaces upon which we work. In many cases it has been found that the principle can be carried too far. The almost total absence of shadows gives to objects a flat appearance. The entire room seems to take on a monotone of intensity, and while no one object attracts the eye by its prominence, there is no place that the eye can find to rest for a moment from the general brightness. The constant strain is often as fatiguing as the worst glare from an exposed light.

The proper combination of the direct and indirect systems into the semi-indirect system has been found to contain the solution for the eyestrain and discomforts produced by either system alone. There is shadow and shading of intensities. The direct component gives shadows and the diffused component fills in the shadows and takes the sharp edge from them. The result is an illumination under which the eye can operate for long periods and there is a sense of being at home which doubtless arises from the fact that this type of lighting duplicates many features of natural daylight of the most pleasing kind.

Automatic Substation Equipment for South African Railways

By W. D. Bearce

Railway Engineering Department, General Electric Company

The South African Railways and Harbors Administration was confronted with the choice of double tracking or electrification in order to accommodate the increasing traffic on the Natal railway lines. After mature consideration the engineers for the Administration recommended electrification from Glencoe Junction to Pietermaritzburg, a distance of 171 miles. It is one of several 3000-volt electrifications which have been installed as a result of the success of the pioneer Chicago, Milwaukee and St. Paul installation in 1915. The present project involved the construction of twelve 3000-volt automatic substations, together with generating and transmission equipment to supply the current. It comprises the largest automatically equipped railway electrification in the world. The economies to be gained and the increase made possible in the speed of trains and in their capacity, together with a description of the details of the apparatus, are given in this article by Mr. Bearce.—Editor.

The Natal main line of the South African Railways and Harbors Administration has been electrified between Glencoe Junction and Pietermaritzburg, a distance of 171 miles.

This is the first railway electrification scheme to be put into operation in South Africa and it is being followed by the electrification of the Capetown Suburban lines, contracts for which have recently been let.

These two schemes were dealt with in reports presented to the Administration by Merz & McLellan which indicated that considerable economies would be secured by electrification, particularly on the initial electric zone, which is now beginning operation.

The Consulting Engineers pointed out that the Natal line was faced with the necessity of double tracking a number of sections, should it be decided to continue with steam operation and that it would be feasible to place electrical equipment in operation in about the same time as would be required to complete double tracking.

It is understood that arrangements are being made for placing the power station in the hands of an Electricity Commission, thus relieving the Railroad Administration of the responsibility of the manufacture and sale of power. The use of 3-phase 50-cycle current facilitates the standardization of all power equipment for railway, industrial and lighting loads.

Assuming the transfer of the power facilities to the Electrical Authority and taking credit for the cost of steam engines and double tracking required if steam operation continued, it appeared that the net capital outlay would be quite small when compared with the annual saving in working expenses resulting from electrification.

There are other incidental advantages not particularly emphasized by the Consulting Engineers in their reports.

(1) *Tunnel Operation*—There are numerous tunnels, some very long and one or more through which it is not feasible to double head steam trains.

(2) *Fire Hazard*—With electrical operation the danger from cinders causing grass fires will be eliminated as well as the expense thereby entailed in applying fire breaks outside the railway fence.

(3) *Branch Line Electrification*—Supplementing the main line electrification it will be possible to electrify short adjoining branches at a comparatively small expense. Many of these have severe grades and are difficult to operate with steam equipment.

(4) *Punctuality of Traffic*—With fewer trains and more uniform speeds it is expected that the traffic will be handled even more punctually than under steam.

(5) *Release of Coal*—The coal now used for locomotive purposes will, under electrification, be available for shipment, and low grade fuel now regarded as waste will be utilized for the power stations.

The freight traffic on this division approximates 20,000 gross tons per day from Glencoe southward, together with some passenger traffic. The estimates for electrical operation, however, were based on the assumption of 30,000 gross tons daily except Sunday in the down direction and approximately half this tonnage in the up direction.

Substations

The South African Electrification is without question the most extensive single installation of automatic substations in any part of the world. Twelve stations have been installed in the electric zone all for complete automatic operation. Standard three-unit sets of 2000 kw. capacity are used in all stations; four stations being equipped with one machine each; seven stations with two machines; and one with three machines.

Three-phase power is generated at Colenso at 50 cycles and is stepped up for transmission purposes to 88,000 volts. At the substations this is reduced to 6600 volts and converted to 3000 volts direct current by the synchronous motor-generators above mentioned. Provision is made for the operation of all of these sets inverted, in case the regenerated current from the locomotive exceeds the requirements of other trains taking power. The three-unit station (Estcourt) is located at the foot of a ten-mile grade averaging about 1 per cent. The average substation spacing is 15½ miles and there is practically no stub-end feed since a substation is located at both Glencoe and Pietermaritzburg.

The equipment for these substations was contracted for jointly by the British Thomson-Houston Company and the International General Electric Company and includes the following:

Five—13,500-kv-a., 6600/88,000-volt forced oil-cooled transformers stepping-up power at the generating station for transmission.

Twenty—2400-kv-a., 88,000/6600-volt oil-cooled transformers stepping-down from the transmission line voltage to motor-generator sets in the substations.

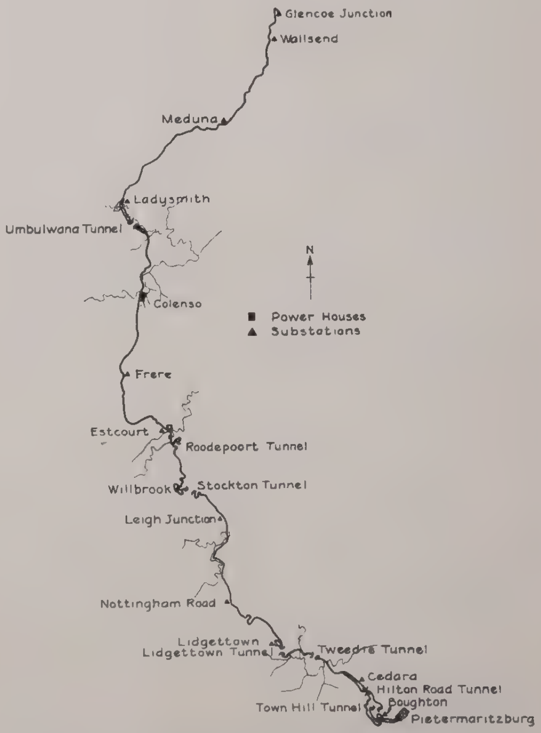


Fig. 1. Map of the South African Railways' Lines Which Have Been Electrified

Twenty-one—2000-kw., 3-unit, 6600 a-c. to 3000-volt d-c. motor-generator sets for the twelve substations built by the British Thomson-Houston Co., at Rugby. Automatic switching equipment furnished in part by the General Electric Co. and in part by the British Thomson-Houston Co. and assembled and tested at Rugby, England.

The power station is located on the Tugela River at Colenso 112 miles from Pietermaritzburg. The equipment includes five turbine-generator sets, each having a continuous rated output of 12,000 kw. at 6600 volts, 3 phase, 50 cycles. This energy is stepped up to 88,000 volts for transmission. The twelve substations located at the following points are supplied over duplicate transmission lines erected about one-half mile apart:

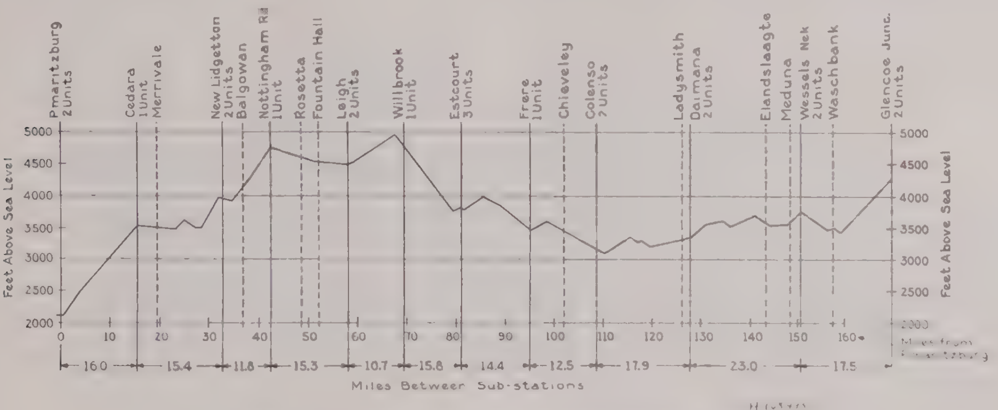


Fig. 2. A Profile of the Glencoe-Pietermaritzburg Line

Glencoe Junction
Wessels Nek
Daimana
Colenso
Frere
Estcourt
Willbrook
Leigh
Nottingham Road
New Lidgetton
Cedara
Pietermaritzburg

The substation at Colenso is fed direct from the 6600-volt power station bus.

Automatic Control Equipment

Each automatic equipment is designed for local and remote control, the operations of starting up and shutting down being effected by two-position switching arrangements at the points of control. For all normal operating conditions, the voltage of the generators will be reduced by field rheostats and equalized with the line voltage before being connected to the feeder. The machine voltage is then automatically brought back to normal potential. Power limiting equipment provides for

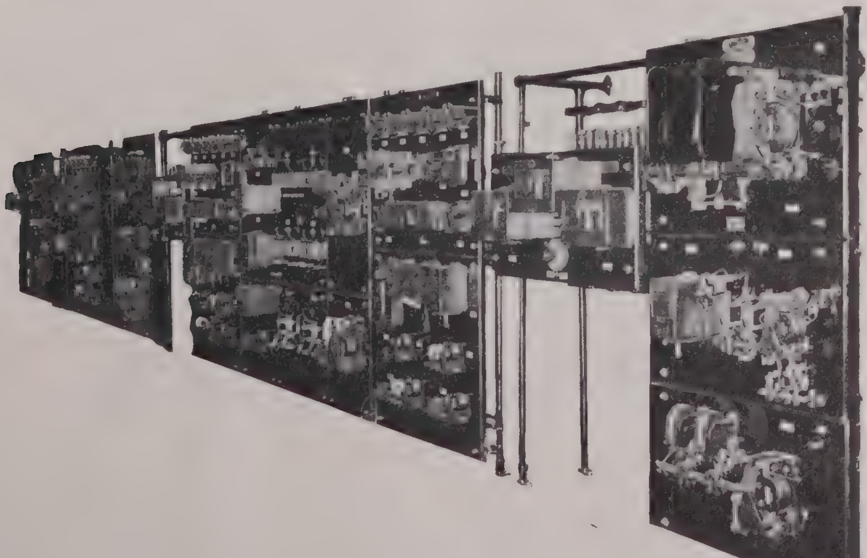


Fig. 3. Automatic Switching Panels for Controlling 2000-kw., 3000-volt Synchronous Motor-generator Sets

reducing the trolley voltage when the load exceeds twice the normal rating of the station. When a short circuit or excessive overload occurs, the station will be disconnected from the feeder and automatically reconnected at a low voltage. If the overload persists after the machine has been connected several times in succession, the station will shut down and will not start again until a relay has been reset by hand.

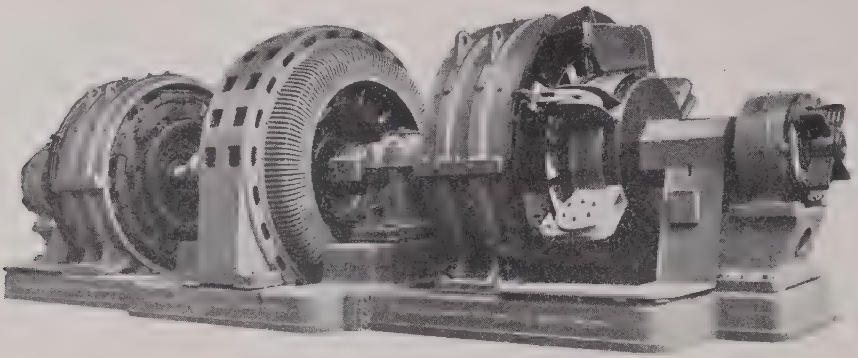


Fig. 4. One of the Standard 3-unit Synchronous Motor-generator Sets for 3000-volt Operation

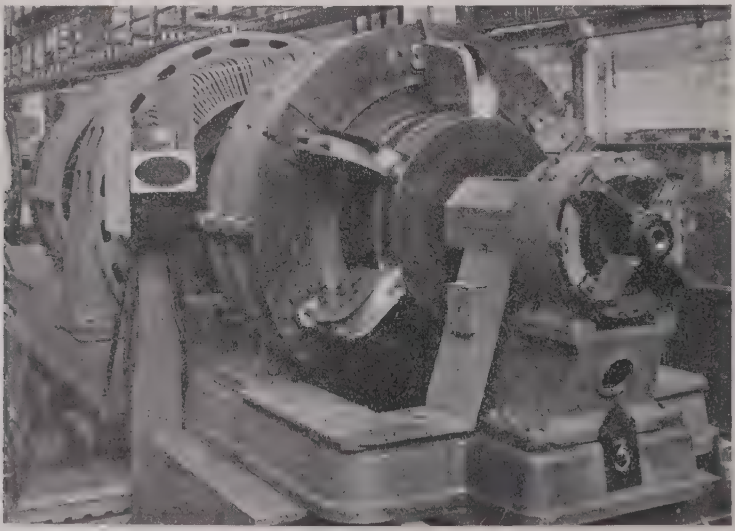


Fig. 5. Synchronous Motor-generator Set on Test

Protective Devices

Protective devices are classified as follows:

a. Those which reduce the load on the machine without disconnecting from either the a-c. or d-c. bus lines
   1. Load limiting relay.
   2. Temperature relay (this changes the calibration of the load limiting relay).

b. Devices which disconnect the d-c. machines but not the a-c.
   3. Temperature relay.
   4. D-c. high-speed circuit breaker.

c. Devices which disconnect both a-c. and d-c. machines and allow automatic restarting.
   5. A-c. undervoltage relay.

d. Devices which disconnect both a-c. and d-c. machines and require inspection before operating again automatically.
   6. High-speed circuit breaker (only when excessive overload persists).
   7. D-c. ground leakage protective relay between ground and machine frame.
   8. Overload relay in synchronous motor circuit.
   9. Overload relays for 88,000-volt line switch.
   10. Ground leakage relay of synchronous motor.

11. Ground leakage relay of step-down transformer.
12. Relay for protecting d-c. generators against loss of excitation.
13. Relay for protecting synchronous motor against loss of excitation.
14. Relay for preventing single-phase starting.
15. Under-speed device.
16. Over-speed device.
17. Starting relay.
18. Bearing temperature relays.
19. Polarity relay.

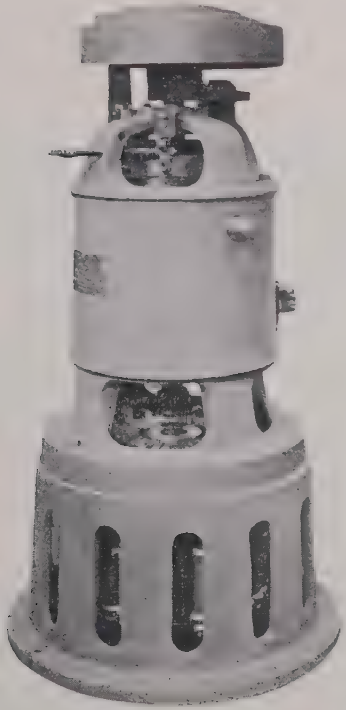


Fig. 6. Torque Motor and Rheostat Which Maintains Practically Uniform Power-factor Under All Conditions of Load

The high-speed circuit breaker is connected between the negative side of the armature and the series winding of each machine. When operating, due to overload or short circuit, the breaker inserts resistance in the main circuit and causes the line contactors on the positive side of the machine to open. Provision is made for resetting this breaker electrically from a distant control station. When regeneration occurs, the operation of a reverse-current relay changes the series winding of the generators and of the exciter of the synchronous motor to give correct running conditions. The machine is controlled at all times by a relay which tends to keep the voltage constant and at normal value by shunt-field regulations. Above a predetermined overload, control is transferred to another relay which causes the potential to be reduced with the increase in load.

Double-unit and Three-unit Stations

In general the scheme for controlling the double-unit station is such that the units operate as far as possible independently of each other. This avoids any interference with the operation of one machine due to trouble on the other. Adequate provision is made for equalizing the load between the two machines when operating in parallel.

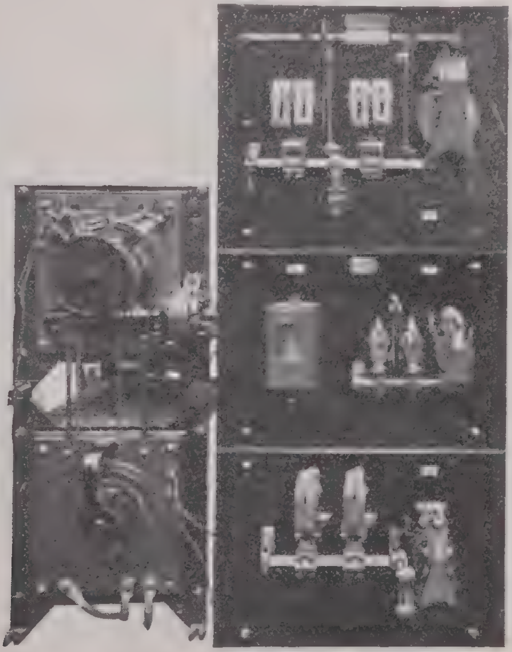


Fig. 7. Motor-operated Rheostats and Field Contactor Panel

Motor-generator Sets

Each motor-generator set consists of a 6600-volt, 3-phase, 50-cycle synchronous motor direct-coupled to two 1500-volt generators designed for series operation together with two exciters; one for the motor and one for the two generators. The five machines are mounted on one bedplate built in three sections and the complete rotating element is supported on four pedestal bearings.

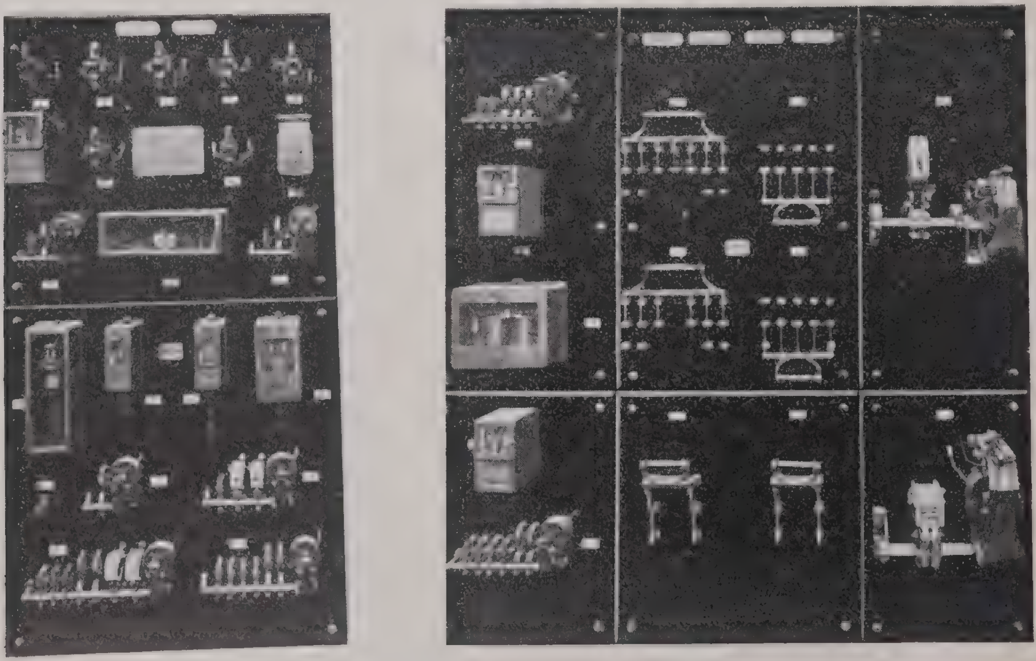
Rating

The direct-current rating of the set is 2000 kw. at 3000 volts, and the equivalent rating of the motor is 2340 kv-a. at 95 per cent power-factor. The overall efficiency for the set is 90 per cent.

The guaranteed temperature rise is 40 deg. C. by thermometer on all parts with the exception of the core of the motor field and the windings upon which 50 deg. is allowed, measured by resistance after a run at continuous full-load rating. Provision is also made for operation at 1.5 times full load for 30 min. succeeding a continuous load run. The machines will also withstand a load of three times normal or 6000 kw. for five minutes and a maximum momentary overload of 3.5 times normal or 7000 kw. Commutation is practically sparkless throughout the full range of operation.

Motor

The synchronous motor is a 12-pole machine running at 500 r.p.m. The armature has a 3-phase star-connected winding of the open slot type with grounded neutral. The coils are form wound and mica insulation is provided between the turns as well as to ground.



Figs. 8 and 9. Relay and Transfer Panel for Motor-generator Automatic Control

Starting

The set is started from the a-c. side from reduced voltage taps on the secondary of the transformer. Connection between the two slip rings supplying the motor field is made automatically by a pivoted arm actuated by centrifugal force. This device is so adjusted that the field is excited when the speed reaches 475 r.p.m., thus pulling the motor into synchronism.

Generators

The direct-current machines have 6 poles and are provided with compound windings, commutating poles and compensated pole face windings to insure sparkless operation at the guaranteed overloads. The series winding of each direct-current generator is in duplicate; one being cumulative to the shunt winding when running as a generator and the other differential under the same condition. Provision is thus made for parallel running under all conditions including reversed operation during regeneration. A feature of the direct-current generators is the use of magnetic blowout coils which enclose the brush gear for the purpose of suppressing arcs on short circuits. A current of air is also supplied by fans on the armature at the commutator end which carry off any copper vapor which may tend to form on short circuits. These machines have been repeatedly short-circuited on test at 3000 volts with a high-speed breaker in circuit and not only have never arced over but show a remarkably small arc at the brushes.

Exciters

The exciter for the direct-current generators is a flat compounded machine rated at 13.2 kw., 110 volts.

The exciter for the synchronous motor is mounted at the opposite end of the set and rated at 36 kw. 170 volts. One of the chief points of interest in this equipment is the method used to give, automatically, the power-factor for best operating conditions over the whole range of loads up to 3.5 times normal. This equipment consists of a torque motor rheostat which regulates a self exciting shunt winding opposed to the main winding of the exciter fields. To secure this result the exciter is provided with four distinct windings; two series and two shunt. One series winding is cumulative and the other differential.

A diverter or shunt is connected across the cumulative series winding when operating normally as a generator. This diverter and the series winding in parallel carry full line current. When the set is operating inverted this winding is automatically short-circuited by a contactor. The differential series winding carries the full line current under all conditions.

The main shunt winding is separately excited from the d-c. exciter and by regulating the current in this winding any desired power-factor on the synchronous motor at no load may be obtained, but when once set, is not altered by changing conditions of load. The second shunt winding is self excited, acts in opposition to the main shunt and cumulative series winding and its strength of field is regulated by the torque motor rheostat.

Torque Motor

The torque motor is a direct-current vertical spindle four-pole machine with a series field winding carrying the main direct current. The armature has a high resistance winding energized at 110 volts from the d-c. exciter. The torque on the armature therefore varies with the direct-current load, but its movement is controlled by a large clock spring, one end of which is fastened to the armature shaft and the other secured to the end shield. The movement of the armature is, therefore, proportional to the line current and it takes up a definite position depending upon the load. The torque motor is mounted on top of the rheostat which it regulates and the vertical shaft carries the rheostat arm, which is provided with two carbon brushes. The rheostat is so graded that there is a minimum resistance or a maximum decompounding action on the exciter at about the middle of its travel. This device does not operate when the set is running inverted.

Power-factor

For best operating conditions of the whole plant, it is necessary to run as nearly as possible at unity power-factor on the main generator over a large range of load and to provide a certain amount of lagging current at no load to balance the capacity of the line.

Without the torque motor, that is, with the natural characteristics of the exciter, it would be possible to maintain a power-factor approximately at unity between full load and three times full load, but at no load the percentage lagging current would be too high. If the field of the exciter were adjusted to give the correct amount of lagging current on no load, then it would be found that while it is still possible to obtain approximately unity power-factor on the overloads, it would be too heavily leading on full load.

In conjunction with the torque motor and rheostat the synchronous motor exciter will give the required characteristic to enable the main generators to run at unity power-factor under all conditions of loading on the line.

The author wishes to acknowledge the courteous assistance of Messrs. Merz & McLellan and through them the kindness of the High Commissioner for the Union of South Africa in reviewing and correcting the information contained in this article. Valuable assistance has also been given by the designing engineers of the British Thomson-Houston Co.

Preliminary Analysis of High-power Radio Broadcasting

By the Bureau of Standards, United States Department of Commerce

The past summer has witnessed a ten-fold increase of power used in many of the broadcasting stations as well as experiments on still higher powers, running up to 50 kw. Measurements on the actual signals delivered by these stations have been made by the Bureau of Standards, and co-operating laboratories. These measurements culminated in special observations on the alternating 50- and 2½-kw. transmission tests by Station WGY on August 22, 24 and 25. Some surprising conclusions can be announced.

The results are remarkable for some things that did not happen as well as for some that did. First and foremost, high power has not resulted in signals of overwhelming intensity. Even the 50-kw. transmission reached many listeners with an intensity which was not noticeably greater than that of many other stations operating on moderate power. Excessive interference or blanketing of lower power stations is another element of the popular picture of "superpower" which has failed to materialize. These results, from the viewpoint of scientific investigation, are regarded as important verification of the calculations of radio engineers, who have consistently maintained that the apprehensions of stifling effects of higher power were wholly unfounded.

The most startling conclusions are in reference to fading, or signal fluctuation. At all distances greater than about 50 miles from a station, actual tests show that the received wave intensity is continually fluctuating, the variation from maximum to minimum being as great as 100 to 1. The ear is notoriously insensitive to intensity changes, otherwise the reception of distant broadcast programs would be quite unacceptable. Increasing the power was found to effect no improvement in the degree of fluctuation. It can, therefore, be definitely stated that high power is not the solution of the fading problem.

For still another reason, the distance over which a broadcast station gives highly satisfactory, dependable service is quite limited. This is the omnipresent background of static and all sorts of electrical disturbance, which require that the radio wave have more than a certain minimum intensity in order to assure reception free from interference. There is an area around every broadcast station within which such perfect reception is assured and beyond which it is not possible to rely on night-time reception free from disturbance. Daytime reception is in general not possible at all beyond this area. This zone of really dependable radio service around each broadcasting station is surprisingly small, but its area is approximately proportional to the station's power. This is found to be the prime reason which makes high power even desirable from the standpoint of improved public reception.

More specific conclusions can not yet be stated by the Department of Commerce on the special 50-kw. tests of August 22 to 25. Further experimentation with high power can be expected. Particular attention is being given to fading in further studies by the Bureau of Standards and co-operating laboratories. More data on the effects of atmospheric conditions which give rise to fading are seen as the only hope of extending satisfactory radio reception to great distances.

The Radio Transmission Developmental Laboratory of the General Electric Company from Which the 50-kw. Was Radiated

A Study of Crystal Structure and Its Applications

PART VII*

THE POWDER METHOD OF CRYSTAL ANALYSIS (Continued)

By Dr. Wheeler P. Davey

Research Laboratory, General Electric Company

The previous installment in this series gave the method of obtaining the diffraction pattern of a powdered crystal and the manner of interpreting the pattern. In this issue the author applies the method to the solution of typical crystals, some of which have already been dealt with in the discussion of the Bragg method. The fact that both methods lead to the same results lends certainty to the conclusions. The next installment will deal with precision measurements of crystal parameters for a study of the application of crystal structure to fields outside of crystallography.—Editor.

The Structure of Typical Alkali Halides

It will be of interest to illustrate the Powder method by showing the interpretation of the diffraction patterns of some of the same crystals by which the Bragg method was illustrated. Figs. 52, 53, and 54 show the diffraction patterns of KCl, NaCl and KI respectively.

The pattern of KCl shows six lines whose spacings decrease in regular fashion. Where a seventh line might be expected, there is an empty space. This corresponds to the description already given(59) for the diffraction pattern of a simple cubic crystal. Trial shows that the interplanar distances corresponding to the various lines of the pattern have, quantitatively, the same ratios as are listed in Table VII for a simple cubic lattice. In a simple cubic crystal there are three families of 1 0 0 planes, parallel respectively to the three axes of the crystal. There are six families of 1 1 0 planes corresponding to the six possible directions for face diagonals. There are four families of 1 1 1 planes perpendicular respectively to the four directions for the body-diagonals of the cube. The chance of a 1 1 0 plane being turned at the correct angle for diffraction is therefore double that of a 1 0 0 plane. The chance of a 1 1 1 plane being turned at the correct angle is one and a half times that of a 1 0 0 plane, etc. Other things being equal, the x-ray beam diffracted from the 1 1 1 planes of the powdered crystal should, therefore, be twice as intense as that from the 1 0 0 planes. The beam from the 1 1 1 planes should be one and one-half times as intense, etc. If we remember that the intensity of the diffracted beam falls off as the angle of diffraction increases, it is evident from Fig. 52 that the relative intensities of the lines actually do correspond to the number of families of the various planes in the crystal. We therefore are justified in assuming that KCl is built up on a simple cubic lattice. A calculation of density made in accordance with equation (30) shows at once that, on the average, *half* a "molecule" of KCl is situated at each corner of the unit-cube. Since the ionic numbers of K^+ and Cl^- are equal, their diffracting powers should be equal, so we conclude at once that they occupy alternate corners of the cube.

The diffraction pattern of NaCl is that already described(59) as characteristic of a face-centered cubic lattice. A calculation of density shows that a whole "molecule" of NaCl must be associated with each point in the face-centered cubic lattice. It will be noticed from Fig. 53 that those planes for which the Miller indices are all odd(60) produce lines in the diffraction pattern which are much weaker than the others. If these relatively faint lines are disregarded, the remaining lines form, quantitatively, a diffraction pattern of a simple cubic lattice whose cube-edge is half that of the face-centered cube. A calculation of density for such a cube shows that, on the average, *half* a "molecule" of NaCl would have to be associated with each point of the simple cubic lattice, i.e., Na^+ and Cl^- might be

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(59) Part VI, p. 586.

(60) Second order diffraction is considered as being a first order beam coming from fictitious planes whose Miller indices are all double those for the actual first order diffraction. Such indices are therefore all even. Third order diffraction is considered as coming from fictitious planes whose indices are three times those for the actual first order diffraction.

* References made to material hitherto published in this series of articles may be readily located from the following table:

Issue	Figs.	Equations	Tables	Footnotes
Part I, Nov., 1924; p. 742	1 and 2	1 to 16	I and II	1 to 21
Part II, Dec., 1924; p. 795	3 to 10	17 to 32	III	22 to 27
Part III, Feb., 1925; p. 129	11 to 22	33 to 37	IV	28 to 42
Part IV, Apr., 1925; p. 258	23 to 28	38 to 41	None	43 to 48
Part V, May, 1925; p. 342	29 to 35	None	None	49
Part VI, August, 1925; p. 586	36 to 51	42	V to VII	50 to 58

assumed to occupy alternate corners of the simple cube. Such a structure would place the Na^+ and Cl^- on two interpenetrating face-centered cubic lattices as in Fig. 29.

This model gives alternate planes of Na^+ and Cl^- for each of those families of planes whose Miller indices are all odd, and gives planes composed of both Na^+ and Cl^- for the other families of planes. If now we assume, as we have already done all along in discussing the Laue and Bragg methods, that Cl^- (ionic number 18) diffracts x-rays more strongly than Na^+ (ionic number 10), then the small intensities of the diffracted rays from the 1 1 1, 3 1 1, 3 3 1, 5 1 1, 3 3 3, - - - - -, planes will be accounted for, for their amplitudes in each case will be the *difference* between the amplitudes of the beams sent out by the planes of Na^+ and of Cl^-. Similar reasoning leads to a structure of the NaCl type for KI. In this case the lines from the planes of odd indices are relatively stronger than for NaCl because of the greater difference in the ionic numbers of K^+ and I^-.

CsI, CsBr and CsCl show much the same sort of progression in their diffraction patterns. Cs^+ and I^- have the same ionic number and are therefore assumed to have equal diffracting power. The diffraction pattern of CsI is that of a body-centered cube. It is concluded from the density that Cs^+ ions occupy the corners of the unit-cube and that I^- ions occupy the body-centers. As the ionic number of the halogen is decreased the degree of interference is lessened between the diffracted rays from the corners of the cube and the center of the cube. CsBr therefore shows a simple cubic pattern, the strong lines of which form a body-centered cubic pattern. CsCl shows a similar sort of pattern except that the lines which are weak for CsBr are relatively stronger for CsCl.

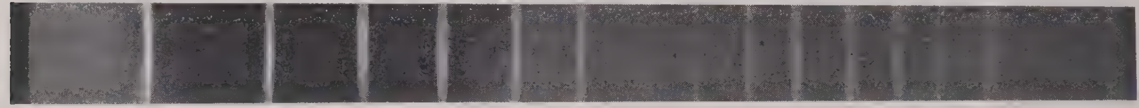

Fig. 52. Diffraction Pattern of KCl

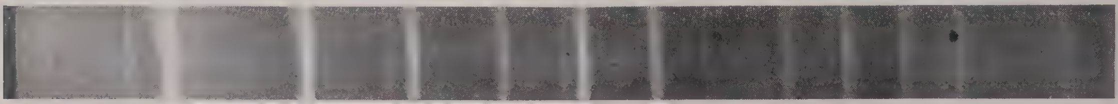

Fig. 53. Diffraction Pattern of NaCl

The Structure of Diamond, Zinc Blende, and Fluorite

Hull has obtained(50) a very complete powder diffraction pattern of diamond using Mo K alpha rays and a photographic film mounted in a complete circle except for a small port hole through which the incident beam entered. The glass tube containing the crushed diamond was at the center of the circle. In this way he was able to photograph every one of the 25 lines which are theoretically possible within an angle of 172 degrees. There should be two more lines between 172 and 180 degrees, but the fog from the incident beam made it impossible to see them clearly. Hull's data are tabulated in Table VIII. Along with his experimental data are given the interplanar distances calculated with the aid of equation (18) from Bragg's value for the side of the unit cube. Every experimental spacing is accounted for, and there are no theoretical spacings left unaccounted for. The chances of any structure other than that of Fig. 7 accounting completely for 25 consecutive interplanar spacings is so remote as to be negligible.

The powder pattern of zinc blend is that of a face-centered cube with strong lines such as to give a diamond cubic pattern if taken alone. The dimensions of the face-centered and diamond cubes are identical. The density shows that a whole "molecule" of ZnS is associated with each point of the face-centered lattice, but that on the average only half a "molecule" is located at each point of the diamond lattice. These facts lead at once to the structure of Fig. 31.

The diffraction pattern of fluorite is that of a diamond cube, and the intensities of the lines are practically the same as in the pattern of diamond. The density shows that, on the average one Ca^{++} or two F^- ions must be associated with each "point" in the diamond lattice. By placing the two F^- ions as in Figs. 32 and 33 the diffraction pattern, the density and the ordinary crystallographic properties of fluorite are all satisfied.

The Structure of Quartz

Quartz offers an interesting example of the possibilities of the Powder method. Its diffraction pattern is that of a simple triangular lattice. The side of the equilateral triangle is $a = 4.89$ A. The height of the unit prism is $c = 5.375$ A, giving an axial ratio $C = 1.10$. Equation (32) gives the density as 0.89 instead of the actual density of 2.69. Evidently the crystal has three times as many SiO_2 molecules as it would have if there were only a single SiO_2 at each "point" of a simple triangular lattice. This means that the crystal must be composed of three interpenetrating simple triangular lattices. The symmetry of the crystal leads us at once to believe that the unit-triangle of each of the basal (0 0.1) planes may be derived from those of the plane below by a rotation of 120 degrees together with a vertical shift of $C/3$ along the Z-axis. Since a rhombohedral lattice is composed of three simple triangular lattices equally spaced along the Z-axis it is natural to guess that quartz might be rhombohedral, but a comparison of the actual diffraction pattern with that calculated for a rhombohedron of the same axial ratio shows that this guess is wrong. It is therefore necessary to assume that although the quartz crystal is made up of three interpenetrating lattices, equally spaced along the Z-axis, yet these are differently situated with respect to each other along the X- and Y-axes than they would have been if the crystal were rhombohedral. The locations of the Si and O on the X- and Y-axes have been determined by McKeehan.(61) His method illustrates the possibilities of the Powder method so well that the results are given below in some detail.

TABLE VIII

HULL'S DIFFRACTION DATA FOR DIAMOND

Miller Indices	Number of Co-operating Planes	SPACING OF PLANES IN ANGSTROMS		Estimated Intensity of Line
		Experimental	Theoretical	
111	4	2.05	2.06	1.00
110	6	1.26	1.26	.50
311	12	1.072	1.075	.40
100	3	.885	.890	.10
331	12	.813	.817	.25
211	12	.721	.728	.40
111 (3) 511	16	.680	.683	.20
110 (2)	6	.625	.630	.10
531	24	.597	.602	.20
310	12	.558	.563	.15
533	12	.538	.543	.06
111 (4)	4	.507	.513	.03
711 551	24	.496	.498	.08
321	24	.473	.476	.20
731 553	36	.462	.463	.15
100 (2)	3	.442	.445	.005
733	12	.432	.435	.003
411 110 (3)	18	.417	.420	.12
751 111 (5)	28	.409	.411	.08
210	12	.397	.397	.05
753 911	36	.389	.391	.08
332	12	.378	.379	.05
931	24	.372	.373	.05
211 (2)	12	.363	.363	.07
933 755 771 311 (3)	48	.358	.358	.20

Fig. 54. Diffraction Pattern of KI

It will be remembered from the discussion of the Laue method (Part III of this series) that the resultant R of waves which have the same wavelength but which differ in phase and amplitude is given by

$$R^2 = (X^2 + Y^2) \qquad (35)$$

where R is the amplitude of the resultant wave, and X and Y are two numbers which represent respectively the sum of the components, taken 90 degrees apart, of the amplitudes of the constituent waves. Equation (37) gave for X and Y respectively

$$\left.\begin{array}{l} N_1 \cos 2\,\pi\, n\, (hx_1 + ky_1 + lz_1) \\ + N_2 \cos 2\,\pi\, n\, (hx_2 + ky_2 + lz_2) \\ + \text{- - - - - - - - -} \\ \text{and} \\ N_1 \sin 2\,\pi\, n\, (hx_1 + ky_1 + lz_1) \\ + N_2 \sin 2\,\pi\, n\, (hx_2 + ky_2 + lz_2) \\ + \text{- - - - - - - - -} \end{array}\right\} \qquad (43)$$

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(61) L. W. McKeehan: *Phys. Rev.* *21*, 206, 503 (1923).

where N_1, N_2 - - - - are the atomic or ionic numbers of atoms or ions in the crystal, n is the order of diffraction, h, k and l are the Miller indices of the atomic plane and $x_1y_1z_1$, $x_2y_2z_2$ - - - - are the co-ordinates of the various atoms in the plane $h\ k\ l$. For a single crystal, the factor of proportionality between the intensity of the x-ray beam and the square of the amplitude of the waves was of the form

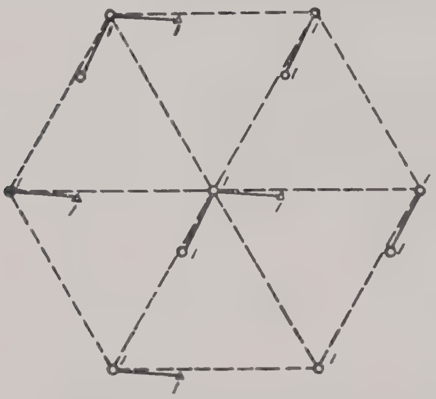

Fig. 55a. Plan View of Successive 0 0 . 1 Planes of McKeehan's Quartz

$$K_1 = \left(\frac{d_{hkl}}{n}\right)^g$$

where d_{hkl} is the interplanar distance and g is an exponent given by Wyckoff as 2.35. McKeehan uses equation (35), but since he is dealing with powdered crystals, his value of K_1 is different from that just given above. The intensity of the diffracted beam of a finely powdered crystal falls off more rapidly with the angle than when a single crystal is used. This necessitates an increase in the exponent g. The intensity of the diffracted beam is proportional to the number, f, of families of co-operating planes in the crystal which can diffract at the given angle, so that it is necessary to introduce f as a factor. Experimentally we measure, not the amplitude, but the intensity of the diffracted beam. Since the intensity, I, depends upon the square of the amplitude McKeehan writes equation (35) in the form

$$I = \frac{f\,d^3_{hkl}}{n}\,(X^2 + Y^2) \qquad (44)$$

The values of f and d depend upon the plane chosen for investigation, i.e., upon the values of h, k and l. It is assumed that the silicon and oxygen are present as ions in the crystal, thus giving Si^{++++} an ionic number $N_1 = 10$ and each O^{--} an ionic number $N_2 = 10$. This assumption is consistent with chemical theory and with calculations on the optical properties of quartz. Various values of $x_1\,y_1\,z_1$, $x_2\,y_2\,z_2$, - - - -, are systematically substituted in the X and Y terms and the relative intensities of the diffracted beams are calculated for various atomic planes in the crystal. McKeehan used the six planes having the largest interplanar spacings, d, in the crystal. The values of $x_1y_1z_1$, - - - - - which gave calculated intensities most nearly in agreement with the results of experiment, were assumed to be the values of the true co-ordinates of the atoms. The value calculated for I from equation (44) is very sensitive to small changes in the values of $x_1\,y_1\,z_1$, - - - -, so that a change in the co-ordinates of 0.1 A from the preferred values gives a calculated result of the wrong order of magnitude.

At first it might seem that an infinite number of choices was possible for the value of each co-ordinate, so that the chance of finding the right values would be negligibly small. It is at this point that the symmetrical characteristics of the crystal are again useful. These impose two limitations on the choice of co-ordinates:

(1) In each molecule the two O^{--} centers are equidistant from the Si^{++++} center so that the three ion-centers lie at the corners of an isosceles triangle.

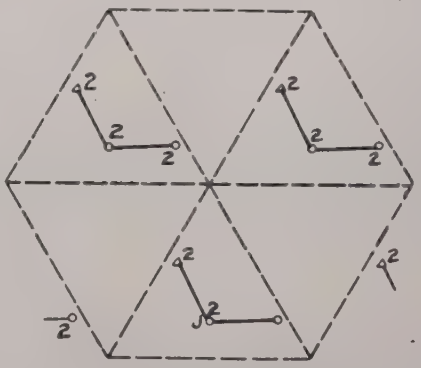

Fig. 55b. Plan View of Successive 0 0 . 1 Planes of McKeehan's Quartz

(2) Each Si^{++++} center is equidistant from the two O^{--} centers in adjacent molecules, the Si^{++++} centers of which belong to different simple triangular lattices from each other and from that of the S^{++++} center under consideration.

It is a matter of experience that the distance of closest approach of atomic centers in crystals usually lies between 1.5 and 3.5 A. In the neighborhood of Si and O this range is between 1.5 and 2.5 A. This serves to reduce the number of choices of co-ordinates still further.

Bragg's values(1) for the parameters of quartz are

$a = 4.89$ A and
$c = 5.375$ A

In terms of these values for the unit-crystal, McKeehan finds that the following values of $x_1 y_1 z_1$, $x_2 y_2 z_2$, - - - -, give the best agreement with the results of experiment. Co-ordinates of ion-centers, grouped by molecules:

Si^{++++} (0, 0, 0)
O^{--} [$0.325\,a, -0.016\,a, 0$] [$-0.325\,a, -0.341\,a, 0$]
Si^{++++} [$0.603\,a, 0.206\,a, 0.333\,c$]
O^{--} [$0.619\,a, 0.547\,a, 0.333\,c$] [$0.944\,a, 0.222\,a, 0.333\,c$]
Si^{++++} [$0.397\,a, 0.603\,a, 0.667\,c$]
O^{--} [$0.056\,a, 0.278\,a, 0.667\,c$] [$0.381\,a, 0.928\,a, 0.667\,c$]

Angles at ion-centers between lines to adjacent ion-centers:

At Si^{++++} between lines to O^{--} of same molecule, - - - - 115 deg. 14 min.
At Si^{++++} between lines to O^{--} of adjacent molecules, - - - - 111 deg. 28 min.

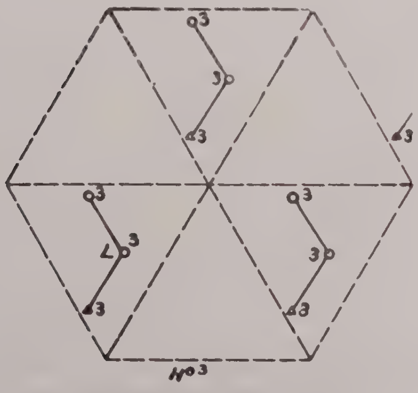

Fig. 55c. Plan View of Successive 0 0 . 1 Planes of McKeehan's Quartz

At O^{--} between lines to Si^{++++} of same molecule and to Si^{++++} of adjacent molecules, - - - - - - 137 deg. 50 min.
Distance between Si^{++++} and O^{--} centers of the same molecule is 1.631 A, of adjcacent molecules is 2.176 A.

These co-ordinates give three equally spaced horizontal layers of ions as described above. A plan of each of these three layers is shown in Fig. 55, (a), (b), and (c). Fig. 55 (d) shows these plans superimposed, thus giving a view of a quartz crystal looking down from the top. A view from the side is given in Fig. 56.

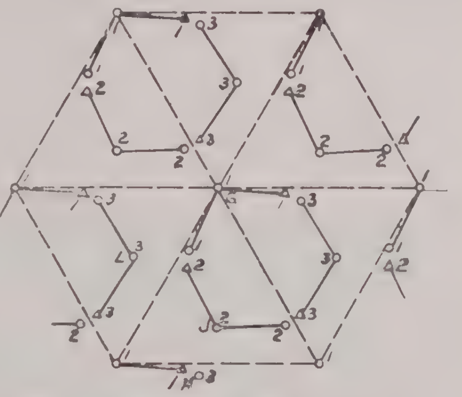

Fig. 55d. Superposition of Figs. 55 a, b, and c

Gibbs(62) has criticized the arrangement of the basal (0 0 . 1) planes in McKeehan's model. Diffraction from these planes is very weak and the first three orders of diffraction have about the same intensity. This is easiest accounted for by assuming each basal plane to be split up into three others—a plane of Si^{++++} sandwiched in between two planes of O^{--}. Gibbs spaces these planes so that the Z-axis of the unit-crystal is divided into nine approximately equal parts. The spacings differ from $C/9$ only enough to permit a weak third order diffraction. Such an arrangement of basal planes, if confirmed, would alter some of the inter-ionic distances in McKeehan's model somewhat, because it would rotate each SiO_2 group slightly about an axis running in the plane containing Si^{++++} from the center of the Si^{++++} to the screw axis of symmetry of the unit structure. This would have the effect of lifting all the O^{--} marked with a circle in Fig. 55 and depressing the O^{--} marked with a triangle, or vice versa.

But in spite of such a change, the structure of quartz differs from the structure of all other compounds described up to this point. In all the crystals so far described, the unit particle has been a single ion. Such crystals have nothing which may properly be called a chemical molecule. For instance each Na$^+$ in NaCl is equally spaced from six Cl$^-$ and each Cl$^-$ is equally spaced from six Na$^+$.

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(62) R. E. Gibbs: *Proc. Roy. Soc. A. 107*,, 561 (1925).

A given Na^+ can hardly be said to "belong" to one of the six Cl^- more than to any of the other five. Such a crystal is an *ionic crystal*, for it is merely a systematic assembly of ions. In quartz each Si^{++++} has two O^{--} which are closer to it than to any other Si^{++++}, so that the "molecule" of $\mathrm{SiO_2}$ has a real existence in the quartz crystal. Such a crystal is a *molecular crystal.*

The Structure of Arsenic

The Powder method is also well illustrated by Bradley's solution(63) of the structure of arsenic. The diffraction pattern is that of a rhombohedron whose axial ratio (in the hexagonal system) is $C=2.81$. Such a rhombohedron may be easiest thought of as a face-centered cube which has been stretched along a body-diagonal. The crystal must contain two interpenetrating rhombohedra of this type in order to give the proper density.

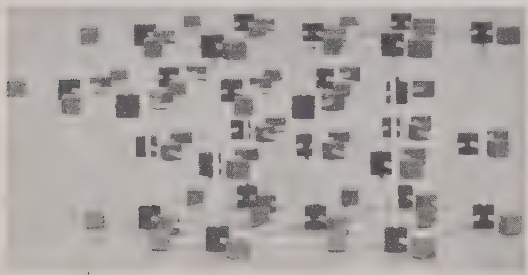

Fig. 56. Side View of Model of McKeehan's Quartz

The symmetry of the crystal demands that the Z-axes (hexagonal system) of the two rhombohedra lie in the same straight line. This means that if we think of these rhombohedra as distorted cubes, then the body-diagonal of one will lie in the same straight line as the body-diagonal of the other. Such a displacement is much like what we have in NaCl. So far, we have considered the face-centered lattice of Cl^- to be displaced along the cube-edge of the Na^+ lattice until the corner of the Cl^- cube was half-way along the edge of the Na^+ cube. A glance at Fig. 29 shows that exactly the same result could have been obtained by displacing the Cl^- lattice along the body-diagonal of the Na^+ cube until the corner of the Cl^- cube was half way along the body-diagonal of the Na^+ cube. Either kind of displacement leads to the ionic co-ordinates (see Part II),

	Na^+	
$m,$	$n,$	$p,$
$m+\frac{1}{2},$	$n+\frac{1}{2},$	$p,$
$m+\frac{1}{2},$	$n,$	$p+\frac{1}{2},$
$m,$	$n+\frac{1}{2},$	$p+\frac{1}{2}.$
	Cl^-	
$m+\frac{1}{2},$	$n+\frac{1}{2},$	$p+\frac{1}{2}.$
$m+1,$	$n+1,$	$p+\frac{1}{2}.$
$m+1,$	$n+\frac{1}{2},$	$p+1.$
$m+\frac{1}{2},$	$n+1,$	$p+1.$

where m, n, and p are any integers, including zero. The two face-centered rhombohedra (distorted face-centered cubes) of arsenic must be related to each other in much the same way, except that the corner of one cannot lie exactly at the center of the body-diagonal of the other. If it did lie exactly at the center, we would have a distorted simple cube, and the diffraction pattern would have to be different from what it actually is. If we use trigonal axes so as to correspond to the cubic axes of our NaCl analogy, the atomic co-ordinates must be

$m,$	$n,$	p
$m+\frac{1}{2},$	$n+\frac{1}{2},$	p
$m+\frac{1}{2},$	$n,$	$p+\frac{1}{2}$
$m,$	$n+\frac{1}{2},$	$p+\frac{1}{2}$
$m+\frac{1}{2}+x,$	$n+\frac{1}{2}+x,$	$p+\frac{1}{2}+x$
$m+1\ +x,$	$n+1\ +x,$	$p+\frac{1}{2}+x$
$m+1\ +x,$	$n+\frac{1}{2}+x,$	$p+1\ +x$
$m+\frac{1}{2}+x,$	$n+1\ +x,$	$p+1\ +x$

The displacement of $\frac{1}{2}+x$ along each of the three axes is equivalent to a displacement along the body-diagonal to some point other than the center. By the use of the co-ordinate x, it is unnecessary to use the factor $\frac{1}{m}$ of equation (41) which was employed in the discussion of the Bragg method. Of course it is possible, if desired, to calculate the value of $\frac{1}{m}$ for any given family of planes from the value of x and the angles between the (trigonal) axes of the arsenic crystal.

Bradley used a slightly simpler, but less general, scheme for calculating the atomic co-ordinates of arsenic than was used by McKeehan for quartz. McKeehan used equations (43) and (44). These give the resultant of two or more waves which differ from each other in both amplitude and phase. Equations (43) resolve each of the waves along the X- and Y-axes, and add up the components along each axis. This gives two vectors at right angles to each other, and, in general, of different magnitude.

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(63) A. J. Bradley: *Phil. Mag.* *27*, 881 (1914).

The square of the resultant of these two vectors is expressed in the usual way by equation (44) as the sum of the squares of the two vectors. Assuming that all the atoms of arsenic are alike and therefore have equal diffracting power, Bradley has to deal with only two wave trains of equal amplitude A in each beam of the diffraction pattern. Let ψ be the phase angle between these two wave trains, Fig. 57. The resultant, R, is evidently

$$2\,A \cos\frac{\psi}{2} = 2A\sqrt{\tfrac{1}{2}(1+\cos\psi)}$$

Since the intensity, I, of the wave is proportional to the square of the amplitude, we may use K_2 as a factor of proportionality and write

$$I = K_2R^2 = K_2\,(2A^2)\,(1+\cos\psi)$$
$$I = K_2A^2\,(2+2\cos\psi) \qquad (45)$$

An empirical expression for the factor of proportionality has already been given in equation (44). Other empirical expressions have been proposed by Bragg.(1) (64) Bradley has used one of these, modifying it only by introducing the factor f to account for the number of co-operating planes in the powdered crystal for any given diffracted beam. His value for K_2 is therefore

$$K_2 = \frac{f}{\sin^2\theta}$$

where θ is the angle of grazing incidence as in equation (1). The value of the phase angle ψ is found in terms of the atomic co-ordinates in the usual way, as follows.

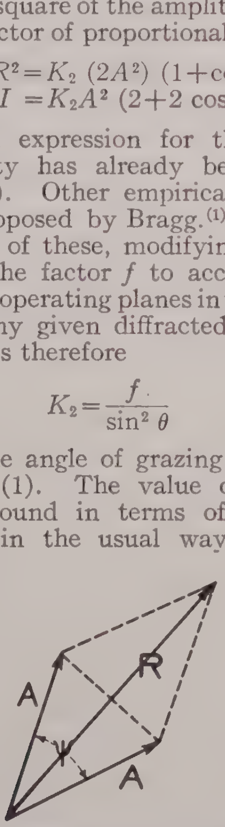

Fig. 57. Resultant of Two Vectors Equal in Magnitude but Different in Phase

The distance between two successive planes is (using trigonal axes), by equation (17)

$$\frac{(h\,x_1+k\,y_1+l\,z_1-1)-(h\,x_2+k\,y_2+l\,z_2-1)}{\sqrt{h^2+k^2+l^2}}$$

In terms of the generalized atomic co-ordinates of arsenic this distance is(65)

$$d = \frac{h\,(x+\frac{1}{2})+k\,(x+\frac{1}{2})+l\,(x+\frac{1}{2})}{h^2+k^2+l^2}$$
$$= (x+\tfrac{1}{2})\,(h+k+l)\,d_{hkl}$$

When $2d_{hkl}\sin\theta$ is an exact multiple of the wavelength used in the experiment, complete "constructive interference" occurs (see discussion of equation (36) in Part III). This corresponds to an angular distance $2\,\pi\,n$. Then

$$\frac{\psi}{2\pi n} = \frac{(x+\frac{1}{2})\,(h+k+l)\,d_{hkl}\,2\sin\theta}{d_{hkl}\,(2\sin\theta)}$$

Therefore the phase difference between x-ray waves diffracted from corresponding planes in the two face-centered lattices of arsenic will be

$$\psi = 2\,\pi\,n\,(x+\tfrac{1}{2})\,(h+k+l)$$

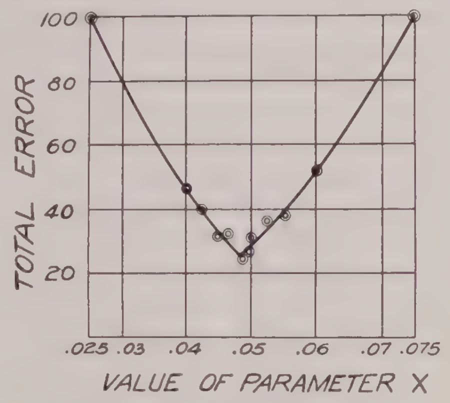

Fig. 58. Graphical Method of Determining x for Arsenic

If we follow the usual convention of incorporating the order of diffraction, n, with the indices so that the nth order diffraction from $h\;k\;l$ is considered as a 1st order beam from a fictitious plane $nh\;nk\;nl$, we have

$$\psi = 2\pi\,(x+\tfrac{1}{2})\,(nh+nk+nl) \qquad (46)$$

Substituting equation (46) in equation (45) we have

$$I = \frac{fA^2}{\sin^2\theta}\Big[2+2\cos 2\pi\big\{(x+\tfrac{1}{2})\,(nh+nk+nl)\big\}\Big] \qquad (47)$$

It is now necessary to solve equation (47) for the various beams diffracted from the crystal using successive values for x. For each value assumed for x, a tabulation is made of (1) the values obtained by experiment for the intensity of each line of the diffraction pattern, (2) the corresponding values calculated from equation (47), and

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(64) *Phil. Mag.*, 27, 881, (1914).

(65) Strictly speaking, we should use $\frac{d_{hkl}}{s}$ where s has the same meaning as in equation (18). For a face-centered structure s will be 1 for planes whose indices are all odd or all even, and ½ for planes with mixed indices.

(3) the difference between (1) and (2). Such a tabulation for one value of x ($x=0.0488$), is shown in Table IX. The total of the differences between the calculated and observed values of intensity is taken as a measure of the error in the value of x. A plot is made, as in Fig. 58, which shows the value of x for which this total "error" is a minimum. The "error" can never be zero because of the difficulties in measuring the observed intensities accurately. The value of x used in Table IX is the one for the minimum of the plot. Bradley saved a great deal of labor in the calculation of x by first getting approximate values. For instance, he says, "Lines $\bar{3}\ 1\ 1$, $4\ 4\ 2$, and $4\ 4\ 4$ entirely

TABLE IX

BRADLEY'S DIFFRACTION DATA FOR ARSENIC

	I	II	III	IV	V	VI
	$\frac{d}{n}$(Obs.) $\times 10^{-8}$ cm.	$\frac{d}{n}$(Calc.) $\times 10^{-8}$ cm.	*hkl.* (trigonal axes)	Order of Intensity Obs.	Order of Intensity Calc.	Error
1	3.555	3.529	111	19	19	..
2	3.18	3.118	$1\bar{1}1$	25	24	1
3	2.780	2.777	200	1	1	..
4	2.054	2.054	220	3	3	..
5	1.891	1.886	$2\bar{2}0$	2	2	..
6	1.781	1.790	311	4	9	5
7	1.764	1.764	222			
8	1.662	1.662	$3\bar{1}1$	12	15	3
		1.614	$\bar{3}11$	..	26	..
9	1.562	1.559	$2\bar{2}2$	8	7	1
10	1.387	1.388	400	5	4	1
11	1.368	1.368	331			
12	1.286	1.291 1.287	$33\bar{1}$ 420	7	8	1
13	1.223	1·227 1.226	422 $3\bar{3}1$	23	23	..
14	1.201	1.201	$4\bar{2}0$	6	5	1
15	1.182	1.177	333	21	21	..
16	1.119	1.119	$4\bar{2}2$	9	6	3
17	1.107	1.109	511			
18	1.089	1.088	$\bar{4}22$	14	14	..
19	1.068	1.066	$5\bar{1}1$	15	15	..
20	1.041	1.039 1.038	$3\bar{3}3$ $\bar{5}11$	20	22	2
21	1.023	1.027	440	24	25	1
		1.005	442	..	28	..
22	0.998	0.997	531	10	10	..
23	0.955	0.955	531	16	13	3
24	0.942	0.943	440	18	18	..
25	0.929	0.9265 0.9265	600 442	11	11	..
26	0.922	0.9215	533			
27	0.908	0.910 0.902 0.902	$5\bar{3}1$ 620 $\bar{5}31$	22	20	2
28	0.891	0.895 0.892	622 442	13	12	1
		0.882	444	..	27	..
29	0.854	0.856	$6\bar{2}0$	17	17	..
					Total Error	25

disappear. For the first line $h+k+l=1$ and the intensity of diffraction will be fairly low for small values of x, but not for medium or high values. Comparing this with $1\bar{1}1$ we again find a small intensity, showing x to be small. The lines 4 4 2, 4 4 4 disappear for

$$x=\left(\frac{2n+1}{2}\right)\left(\frac{1}{h+k+l}\right)$$

The smallest values giving zero intensities are $x=0.05$ and $x=0.15$ for 4 4 2, and $x=0.0417$ and $x=0.125$ for 4 4 4. The line 2 0 0 is by far the brightest on the film. x must therefore be much less than 0.25 for which value the beam from 2 0 0 would disappear. The line 2 2 0 is the third strongest. It would disappear for $x=0.125$ or 0.375, therefore x must be considerably less than 0.125. A value in the neighborhood of $x=0.04$ or 0.05 will fit in with all these facts."

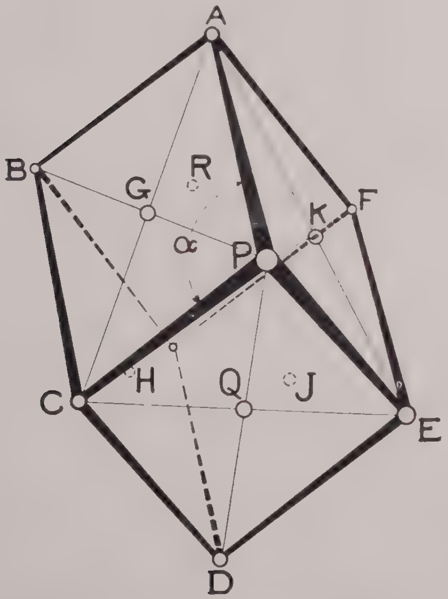

Fig. 59a. Structure of Arsenic—One of the Face-centered Rhombohedra

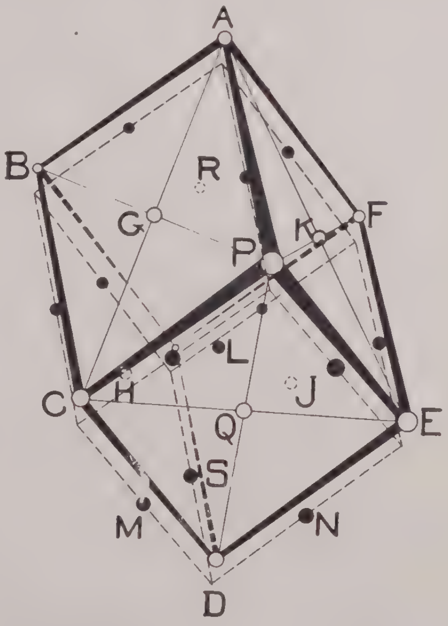

Fig. 59b. Structure of Arsenic—Both of the Face-centered Rhombohedra

It was brought out in Part II that many lattices might be considered to belong to one of two or more crystal systems, depending only upon the point of view. Arsenic is an excellent example of this. We have already considered it as being made up of two slightly distorted face-centered cubes, i.e., as two interpenetrating face-centered rhombohedra with trigonal (distorted cubic) axes of reference. One of these face-centered rhombohedra is shown in Fig. 59a. The two together are shown in Fig. 59b. The edge *A B* of the unit face-centered rhombohedron is $a_1=5.60$ A and $x=0.0488\ a_1$. The angle between any two of the axes is $\alpha=84$ deg. 36 min. Such a structure may also be referred to a second set of trigonal axes which lie along the face-diagonals of the rhombohedra described above. Since α is less than 90 deg., the longer of the face-diagonals must be used. The edges of the new rhombohedra lie along these new axes, and have a length equal to half the face-diagonals of the old rhombohedra. The long body-diagonals of the new rhombohedra are identical with the long body-diagonals of the corresponding old rhombohedra. From this point of view, arsenic is built up of two interpenetrating simple rhombohedra. One of these is shown in Fig. 59c. A portion of the other is shown in Fig. 59d. The side *A G* is $a_2=4.145$ and x becomes $0.054\ a_2$. A structure similar to arsenic has been described in the literature as being made up of two interpenetrating fragmentary simple rhombohedra whose axes are identical with those of the face-centered rhombohedra described above. The edges are parallel to the edges of the face-centered rhombohedra but are only half as long.

Each of these fragmentary simple rhombohedra has half its corners missing so that if x had been zero the combined structure would have been a complete simple rhombohedron. From this viewpoint arsenic is built up of two interpenetrating fragmentary simple rhombohedra of side $a_3 = 2.80$ A and $x = 0.097\ a_3$. If now the origin of co-ordinates of the original face-centered rhombohedron of arsenic is shifted to any one of the three adjacent corners of the unit structure, the crystal appears as a special case of the triclinic system (see Part II), in which all three axes are of equal length and two of the three axes make equal angles with each other. Two of these three structures turn out to be duplicates, so that for every rhombohedral structure so far described for arsenic we have two possible face-centered triclinic lattices. Lastly, any rhombohedron may be thought of as being built up of three interpenetrating simple triangular lattices, and thus it may be considered to belong to the triangular (hexagonal) system. The diffraction pattern of arsenic is an exact match with the theoretical pattern for a rhombohedron such that the side of the unit triangle is 3.75 A and the axial ratio is 2.81. This axial ratio is somewhat larger than that for a face-centered cube (considered as a rhombohedron, a face-centered cube has an axial ratio of 2.45) so that the rhombohedron is a face-centered cube which has been stretched along its body-diagonal. This therefore agrees with the first interpretation given of the structure of arsenic. The density shows that arsenic is composed of two such interpenetrating rhombohedra. If the simple rhombohedra of Fig. 59 are considered from the point of view of the triangular system, they lead to the same size of unit-triangle and the same axial ratio as are given above.

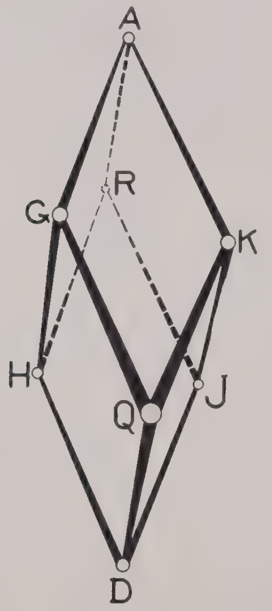

Fig 59c. Structure of Arsenic—One of the Simple Rhombohedra

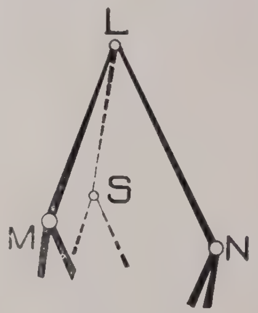

Fig. 59d. Structure of Arsenic—A Portion of the Second Rhombohedron

Altogether, we have seen how the structure of arsenic can be expressed, without undue complication, in any one of eight different ways. Such an embarrassing freedom of choice in the description of a crystal structure sometimes makes it a little hard to correlate the various statements in the literature. This is one of the reasons why models of crystal structure, built to scale, are indispensable to workers in this subject.

(*To be continued*)

A Short Method of Calculating Flywheels

WITH REFERENCE TO RECIPROCATING AMMONIA COMPRESSORS DIRECT-CONNECTED TO SYNCHRONOUS MOTORS

PART II

PRACTICAL APPLICATIONS

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In Part I, which appeared in our August issue, the author traces the development of careful, intelligent flywheel design from the earliest efforts of Boucherot in 1904, to present day practice. Part II concludes the study of flywheel design presented by the author. In this issue there is a discussion of a set of curves which has been in use since November, 1921, and following the discussion of these curves the author demonstrates, by a practical example, the rapidity and accuracy of this method.—EDITOR.

Preparation of Curves

The method of estimating flywheels about to be described can be used only when the compressor belongs to a standard class for which a set of curves has been prepared. The majority of ammonia compressors belong to one of the three following classes:

(1) Single cylinder, double acting (both ends of the cylinders operating between the same pressures).

(2) Two cylinder, single acting with cranks at 180 deg., having the same size cylinders, operating between the same pressures.

(3) Two cylinder, double acting with cranks at 90 deg., having the same size cylinders, operating between the same pressures.

The curves included in this paper are applicable only to compressors which belong to one of the above three classes. In constructing these curves, the angular deviation, θ, was calculated, using equation (1). The torque pulsation was obtained from the angular deviation by the formula,

$$\text{Torque} = T_s\theta + T_d\frac{d\theta}{dt} \qquad (4)$$

As long as the power-factor remains approximately unity, the current pulsation is directly proportional to the torque pulsation, and the per cent current pulsation is equal to the per cent torque pulsation.

The indicator cards used in the preparation of the standard curves are shown in Fig. 6.

The curves are all plotted with abscissa,

$$x = \frac{0.8\,WR^2\,S^4}{10^5\,P_o f} \qquad (2a)$$

Incidentally, it is interesting to notice that if the natural frequency is given by the formula

$$F = \frac{35{,}200}{S}\sqrt{\frac{P_o f}{WR^2}} \qquad (5)$$

then, neglecting the efficiency of the motor,

$$x = 10\left(\frac{S}{F}\right)^2 \qquad (6)$$

The ordinate of the curve is given by the formula

$$y = \frac{\textit{current pulsation}}{\rho} \qquad (7)$$

where $$\rho = \frac{\textit{i. h.p. of compressor}}{\textit{rated h.p. of motor}} \qquad (3)^{(5)}$$

where $S = r.p.m.$

WR^2 = total flywheel effect of both the motor and the compressor flywheel.

P_o = constant furnished by the motor builder, representing the synchronizing torque expressed in kw. per electrical radian.

β = pull-in torque due to the amortisseur winding of the synchronous motor with full voltage applied, at 95 per cent speed, expressed as a fraction of the full load rated torque. (If this torque is 50 per cent $\beta = 0.5$.)

f = frequency of alternating-current supply.

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(5) The indicated horse power of the compressor may be estimated approximately by the formula.

i.h.p. $= k_1 k_2$ (*Vol. of one cyl. in cu. in.*) (*Speed in r.p.m.*)

The constant k_1 depends upon the shape of the indicator card. For cylinders with 2 per cent clearance.

Pressure, 30 lb. to 215 lb. gauge—$k_1 = 0.000211$

Pressure, 20 lb. to 185 lb. gauge—$k_1 = 0.000176$

The constant (k_2) depends upon the number of compression strokes per revolution and, for the different classes of compressors, is as follows:

For compressors of Class 1, $k_2 = 2$

For compressors of Class 2, $k_2 = 2$

For compressors of Class 3, $k_2 = 4$

The curves are plotted with several parameters:

l = ratio of connecting rod length to crank length.

$$\lambda=\frac{40\,\beta\,kw.}{P_o\times poles} \qquad (8)^{(6)}$$

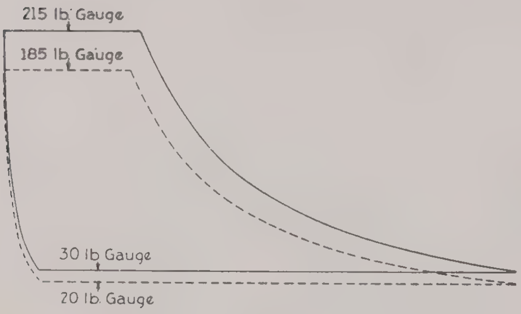

Fig. 6. Indicator Card

Compression Exponent, $n=1.3$
Expansion Exponent, $n=1.1$
Clearance = 2 per cent

There is a third parameter, Q, which for Class 1 is,

$$Q_1=\frac{6.5\,W\,S^3r^2\,10^{-8}}{i.h.p.\,of\,Compressor} \qquad (9)$$

Class 2—

$$Q_2=Q_1 \qquad (10)$$

Class 3—

$$Q_3=\frac{Q_1}{4l} \qquad (11)$$

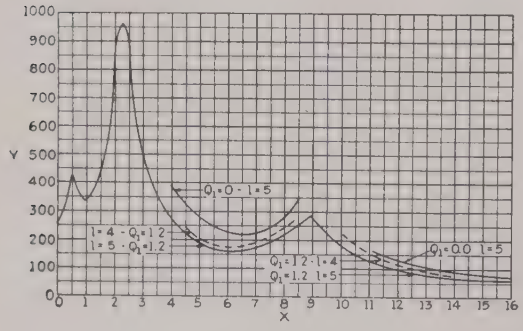

Fig. 7. X-Y Curves for Special Case of $\lambda=0.1$

The lower curve is not changed appreciably in the range from $x=4$ to $=8$ and from $x=10$ to $x=16$ by a change in λ from 0.1 to 0.05.

Where W = Weight of reciprocating parts of each cylinder (includes approximately two-thirds of connecting rod weight).

r = Radius of crank in feet.

Discussion of the Curves for the Various Classes

Class 1: There are very few compressors of this class. Fig. 7 shows the characteristic x-y curve for compressors of this class. It is chiefly interesting for the prediction of what the current pulsation will be when one cylinder of a two-cylinder double-acting compressor is disconnected.

Class 2: The majority of compressors belong to this class and, therefore, more time has been spent in the preparation and analysis of x-y curves for two-cylinder single-acting compressors than for the others. Fig. 8 shows a group of curves based on normal pressure condition (20 lb. to 185 lb. gauge). The scale has been arranged so that the peaks of the curves will remain on the paper. Due to this small scale, the difference could not be seen if maximum pressures had been used (30 lb. to 215 lb. gauge).

Effect of Ratio of Connecting Rod Length to Crank Length—As mentioned before, due to the use of several wrong crank effort diagrams, it was originally thought that l had a large effect on the curves for this class of compressors. Later calculations showed that one set of curves drawn for $l=5$ could quite accurately be used over a range of from $l=4$ to $l=6$.

Effect of Weight of Reciprocating Parts—However, the diagram shows very clearly that the weight of reciprocating parts has a decided effect on the amount of WR^2 required for a given current pulsation. The scale of Fig. 8 is not sufficiently spread out for accurate work. Fig. 9 shows the same curves to a larger scale.

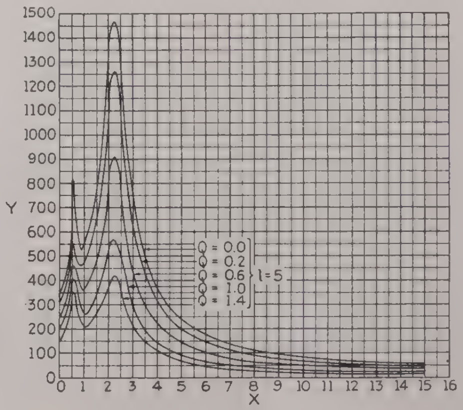

Fig. 8. Hypothetical X-Y Curves (7)

Pressures 20 lb. to 185 lb. gauge

Small Changes Due to l Now Noticeable—It will be noticed that l has a negligible effect with compressors having proportionately light reciprocating parts, but has a small effect when the reciprocating parts are proportionately heavier.

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(6) This parameter was first suggested by H. V. Putman on September 16, 1922.

Effect of Change of Pressure—Fig. 10 is the same as the preceding figure, except that the pressures are 30 lb. to 215 lb. gauge.

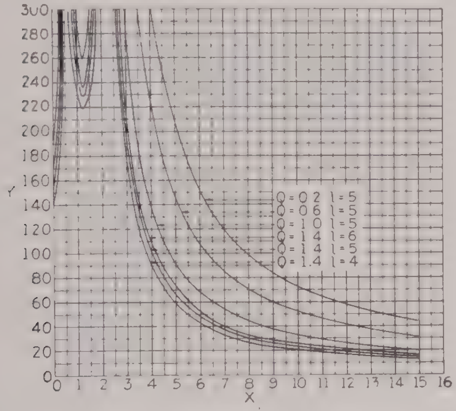

Fig. 9. **Hypothetical X-Y Curves** (7)
Pressures 20 lb. to 185 lb. gauge

Best Weight of Reciprocating Parts—Both these curves indicate that the heavier the reciprocating parts the less the current pulsation. But, there is a weight of reciprocating parts for which the current pulsation is a minimum and any increase beyond this will increase the current pulsation. This is illustrated in Fig. 11.

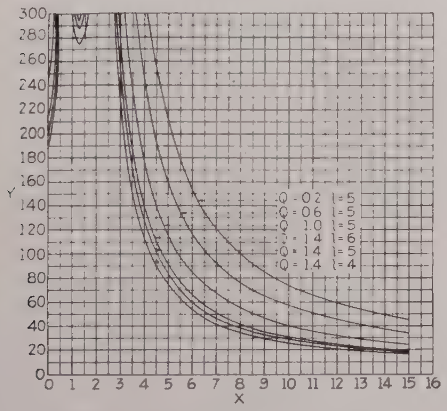

Fig. 10. **Hypothetical X-Y Curves** (7)
Pressures 30 lb. to 215 lb. gauge

The weight of reciprocating parts to give the lowest current pulsation would be calculated by letting $Q_2 = 1.4$, in equation (9) and (10), and solving for W.

Variation Due to Shape of Indicator Card—This small effect which the shape of the indicator card has on the shape of the x-y curve is illustrated in Fig. 12, where the solid lines are drawn from the cards for maximum pressures and the dotted lines are drawn from the cards for normal pressures. Although the value of y for these two sets of curves is about the same, it should be pointed out that the current pulsation is equal to ρy and will be considerably larger for the maximum condition because the indicated horse power is larger.

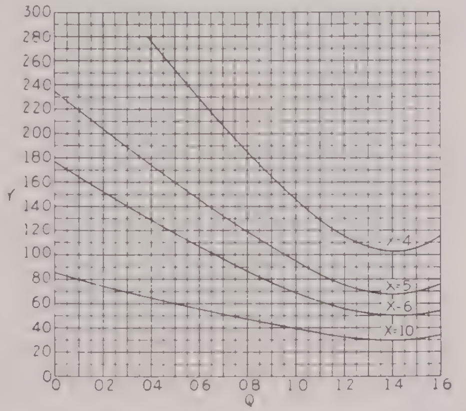

Fig. 11. **Variation of Current Pulsations with Q, $l = 5$** (7)
Pressures 20 lb. to 185 lb. gauge

Effect of Damping Due to Amortisseur Winding of Synchronous Motor—Before discussing the effect of the amortisseur winding of the motor, it seemed good to eliminate as many of the compressor parameters as possible. It has been found, empirically,

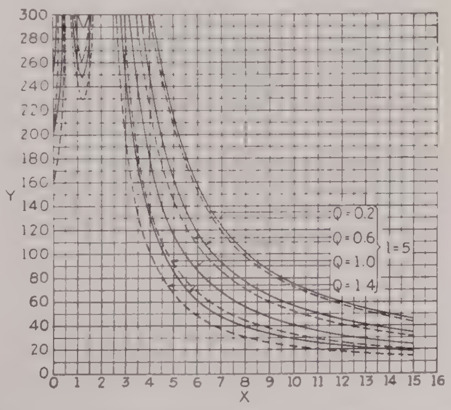

Fig. 12. **X-Y Curves Showing Effect of Change in Pressure** (7)
- - - - - - - - - 20 lb. to 185 lb. gauge
———————— 30 lb. to 215 lb. gauge

that the following relation holds approximately (within about 10 per cent) for compressors of Class 2.

$$y=y_1\left[1+2.5\left(\frac{1.4-Q_2}{1.4+Q_2}\right)\right] \qquad (12)$$

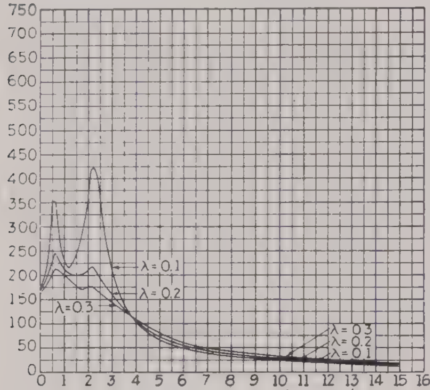

Fig. 13. Showing Effect of Amortisseur Winding (7)

where y_1 is the ordinate from the curve calculated with a weight of reciprocating parts corresponding to $Q_2=1.4$; whereas, y is the ordinate for any other compressor having Q_2 in the range from zero to 1.4. This expression is only applicable in the range $x=1.5$ and above.

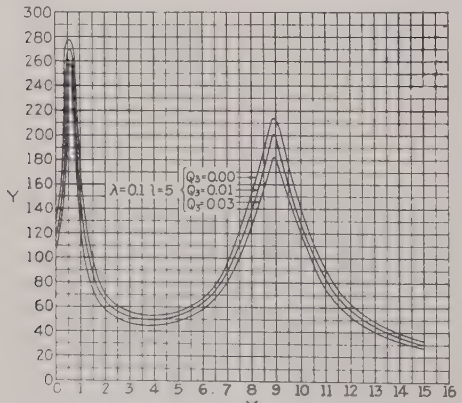

Fig. 14. Effect of Weight of Reciprocating Parts (9)
Ordinates represent special case of $l=5$

Fig. 13 shows curves for compressors of Class 2, with y_1 plotted against x for various values of λ, where

$$\lambda=\frac{40\,\beta\text{ kw.}}{P_o\times poles} \qquad (8)$$

The parameter λ is the coefficient of damping torque due to the amortisseur winding of the synchronous motor. It is difficult to build very low speed synchronous motors with a high value of pull-in torque. Since λ is the product of the pull-in torque and the speed and since the speed is inversely proportional to the number of poles, λ has a low value for low speed machines and a high value for high speed machines.

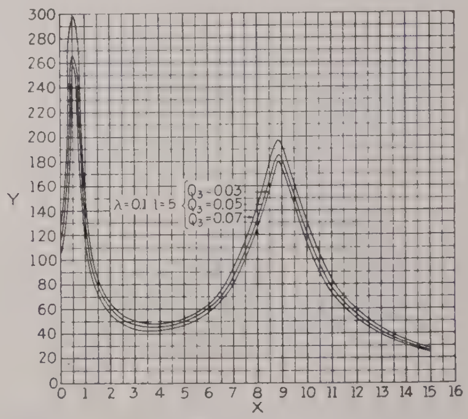

Fig. 15. Effect of Weight of Reciprocating Parts (9)
Ordinates represent special case of $l=5$

A 200-r.p.m., 60-cycle motor, having approximately 50 or 60 per cent pull-in torque at 95 per cent speed, due to the amortisseur winding, with full voltage applied, would have a coefficient of damping torque,

$$\lambda=0.3 \text{ approx.}$$

A 100-r.p.m., 60-cycle motor, having approximately 36 per cent pull-in torque, as defined above, would have a coefficient of damping torque,

$$\lambda=0.1 \text{ approx.}$$

It can be seen from Fig. 13, that the higher values of λ are desirable at the peaks of the curve, but that the curves for different values of λ cross at approximately $x=4$, beyond which the current pulsation is increased by a high value of λ.

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(7) Characteristic curves for a Class 2, Two-cylinder, Single-acting Compressor Cranks at 180 deg. (Figs. 8-13.)

Compression exponent, $n=1.3$. Expansion exponent, $n=1.1$.

$$\lambda=40\left(\frac{\beta\times\text{kw.}}{P_o\times\text{Poles}}\right)=0.1$$

$$X=\frac{0.8\times WR^2\times S^4}{10^8\times P_o} \qquad Q=\frac{6.5\times10^{-8}\times WS^3R^2}{\text{Indicated h.p.}}$$

$$Y=\frac{\text{\% Current Pulsation}}{\rho} \qquad \rho=\frac{\text{Indicated h.p.}}{\text{Rated h.p.}}$$

The ordinates (y_1) represent special case, $Q_2=1.4$.

For values of l from 4 to 6 and values of Q from 0 to 1.4 the ordinate y can be obtained approx. (within 10 per cent) by the empirical formula,

$$y=y_1\left[1+2.5\left(\frac{1.4-Q_2}{1.4+Q_2}\right)\right] \quad \text{Holds only when } x>1.5$$

Janet(8) in 1912, discussed this increase in current pulsation due to increased damping torque, and made the following statement:

> "This was first discovered by M. Görges, who gave the following physical reasons for it:
>
> 'The increase of the damping torque, which in every case decreases the angular deviation, thereby reduces the inertia forces furnished by the flywheel. Since the effect of the flywheel is reduced, the irregularities of the crank effort are transmitted back into the electrical system and cause increased fluctuations of the meter needles'."

From this it can be seen that too much damping, although it reduces the angular deviation, might in some cases be a disadvantage, because it would augment the electric current pulsation.

It should be *particularly noted* that Fig. 13 is drawn with much heavier reciprocating parts than are usually encountered. It shows the limit of what can be accomplished by weighting the reciprocating parts and increasing the damping torque. In the calculation of standard machines, points should not be taken from these curves, Fig. 13, unless the correction factor for lighter values of Q_2 is applied. For accurate work, refer to the particular values of Q_2 and l given in the preceding diagrams where the scale is much larger.

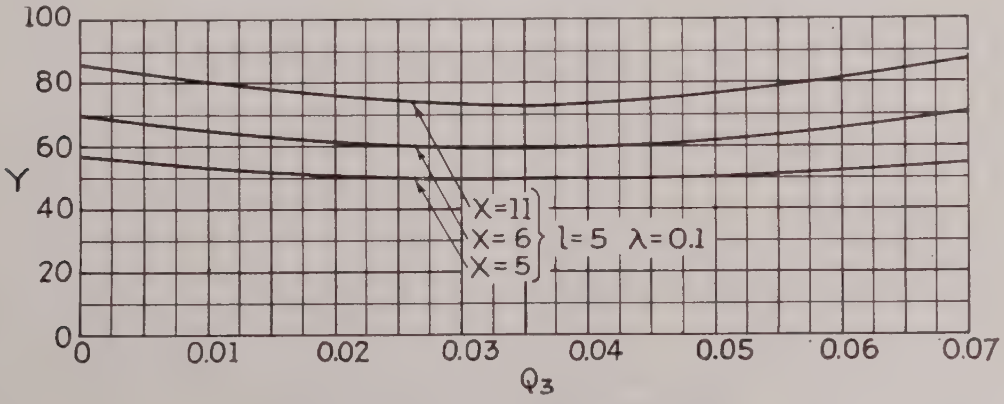

Fig. 16. **Effect of Weight of Reciprocating Parts (9)**

Class 3: In Fig. 14 the "valley" between $x=1$ and $x=7$ is due to the fact that with cranks at right angles the impulses, coming twice a revolution, cancel out if the cylinders are exactly the same size and operate between the same pressures. Tests with oscillographs have, in some cases, shown a second harmonic in the current pulsation of 10 or 20 per cent, due to the fact that the impulses of the two cylinders were not exactly similar. An analogous case is the rough running of an automobile engine when one cylinder fires weaker than the rest. If the compressor is accurately made and maintained in proper adjustment, there is no great cause for worry on this account.

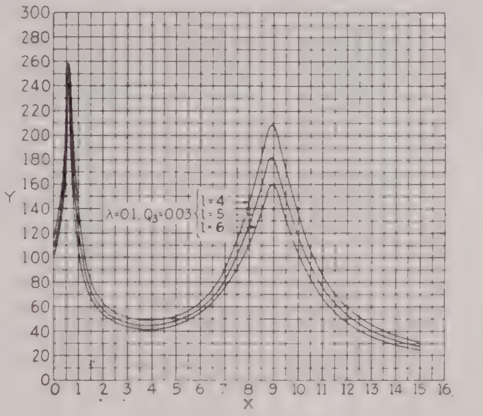

Fig. 17. **Effect of Ratio of Connecting Rod Length to Crank Length (9)**
Special Case of $Q_3=0.03$

Effect of Weight of Reciprocating Parts—The curves, Fig. 14, are all plotted for $l=5$, $\lambda=0.1$, but with different values of Q_3; where

$$Q_3=\frac{6.5\,W\,S^3\,r^2\,10^{-8}}{4\,l\,(i.\,h.p.)} \qquad (11)$$

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(8) Vol. 3 of "Lecons d'Electrotechnique Generale," by P. Janet, 1912.

(9) Representative Curves for a Class No. 3, Two-cylinder Double-acting Compressor. Cranks at 90 deg. (Figs. 14-18).
Clearance =2 per cent. Compression exponent, $n=1.3$.
Expansion exponent, $n=1.1$. Pressures 20 lb. to 185 lb. gauge.

$$X=\frac{0.8\times WR^2\times S^4}{10^8\times P_0} \qquad Y=\frac{\%\ \text{Current Pulsation}}{\rho}$$

The current pulsation for compressors of Class 3 is a minimum when $Q_3=0.03$ approx. Fig. 15 shows the same curves for values of Q_3 greater than 0.03 and less than 0.07.

Fig. 16 shows the cross-sections of the curves at various values of x. These curves were drawn in order to show graphically that there is a minimum value of y corresponding to a certain value of $Q_3=0.03$(10) approx.

Effect of Ratio of Connecting Rod Length to Crank Length—The value of l is much more significant for compressors of Class 3 than for compressors of Class 2. Fig. 17 shows the "x—y" curves for various values of l. It will be noticed that the longer the connecting rod, the less the current pulsation.

Effect of Coefficient of Damping Due to Amortisseur Winding of Synchronous Motor—It seemed wise, before studying the variations of the parameter λ, to eliminate the other parameters from the curves by means of an empirical equation. It will be found that the curves for Class 3 can approximately be represented by plotting one curve y_1 with values of $l=5$ and $Q_3=0.03$.

The ordinates y for any other values of l and Q_3 within the limits can be obtained approximately (within about 10 per cent) by one or the other of the following equations:

$$y=y_1\left[1+\ 0.2\left(\frac{.03-Q_3}{.03+Q_3}\right)\right]\left[0.35+\frac{3.25}{l}\right] \quad (13)$$

when $x>2$ and $0<Q_3<0.03$

$$y=y_1\left[1+0.25\left(\frac{Q_3-.03}{Q_3+.03}\right)\right]\left[0.35+\frac{3.25}{l}\right] \quad (14)$$

when $x>2$ and $0.03<Q_3<0.07$

These equations cannot be used except for values of x greater than 2.

Fig. 18 shows curves for compressors of Class 3 with y_1 plotted against x for various values of λ, the coefficient of damping torque. It should be remembered that these curves are plotted for the *special* case, $Q_3=0.03$ and $l=5$, and the *correction factor* must be used for compressors with other values of l and Q_3.

A great many flywheels are applied to this class of compressor corresponding to values in the neighborhood of $x=2$. It will be noticed that a high value of damping torque increases the current pulsation in this range and also in the range above $x=15$.

But, it is also evident that a high damping torque is very beneficial in reducing the peak at $x=9$. With moderately high speed (200 r.p.m.) air compressor motors, it is easy to get a coefficient of damping, $\lambda=0.2$ or above. Moderately high speed motors (200 r.p.m.) cannot be built for values of x less than approximately 2 or 3, and it is therefore evident that when used with simple two-cylinder double-acting compressors (Class 3), it is not necessary to make any flywheel calculations if a current pulsation of less than 100 per cent is permissible. In other words, such a machine, if properly braced to withstand vibration, would run successfully on a large power system, even if the natural frequency of vibration were exactly equal to the revolutions per minute.

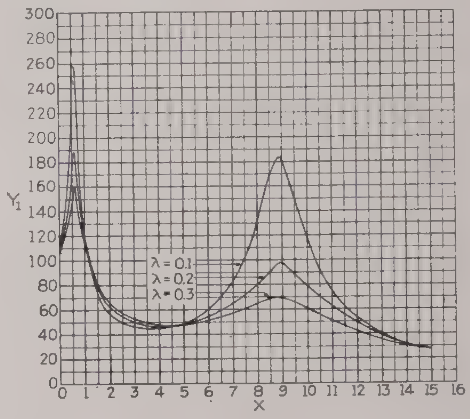

Fig. 18. Effects of Amortisseur Winding (9)

The ordinates y_1 represent the special case of $l=5$ and $Q_3=0.03$. For other values of l from 4 to 6 and Q_3 from 0.0 to 0.07, the ordinate y can be obtained approximately (within 10 per cent) by the empirical formulas:

$$y=y_1\left[1+0.2\left(\frac{.03-Q_3}{.03+Q_3}\right)\right]\left[0.35+\frac{3.25}{l}\right]$$ Which holds only when $x>2; 0<Q_3<0.03;$ and

$$y=y_1\left[1+0.25\left(\frac{Q_3-.03}{Q_3+.03}\right)\right]\left[0.35+\frac{3.25}{l}\right]$$ Holds only when $x>2$ $0.03<Q_3<0.07.$

Class 3 Compressors with One Cylinder Disconnected—Whenever one cylinder of a Class 3 compressor is disconnected, it automatically becomes a compressor of Class 1, and the operation must be checked with the curves for Class 1.

Use of Curves

It should again be emphasized that these curves cannot be used for compressors which do not belong to one of the three foregoing classes. Other curves have to be prepared for compound compressors, three-cylinder compressors, or compressors operating under unbalanced conditions. Warning is also given that it is risky to use these curves for

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(10) It may be noticed that the best weight of reciprocating parts is the same for all three types of compressors, since

$$Q_3=(Q_1 \text{ or } Q_2)\frac{(i.h.p.)_{1 \text{ or } 2}}{(i.h.p.)_3}\cdot\frac{1}{4l}=\text{approx.}\frac{Q_1 \text{ or } Q_2}{40}$$

for the same weight per cylinder. For the minimum current pulsation,

$$Q_1=Q_2=1.4,\ Q_3=1.4/40=0.035 \text{ approx.}$$

ratios of connecting rod length to crank length outside the limits $l=4$ to $l=6$, or for weights of reciprocating parts outside the limits of Q, which have been calculated.

The application of these curves to a practical problem usually consists of determining the amount of WR^2 required to keep the amplitude of current pulsation within 66 per cent of the motor rated current. The procedure is as follows. Calculate

1. $\rho = \frac{i.h.p.\ of\ compressor}{h.p.\ of\ motor}$ (3)(11)
2. $y = \frac{60}{\rho}$ (7)(12)
3. $l = \frac{connecting\ rod\ length}{crank\ length}$
4. Calculate Q from equations (9), (10) or (11).
5. Calculate λ from equation (8)
6. Turn to the curve for the class of compressors under consideration and select the value of x corresponding to the values of y, l, Q and λ which have been determined.
7. Required $WR^2 = \frac{P_o f\, 10^8}{0.8\, S^4} \cdot x$

In calculating the flywheels for compressors of Class 1 or Class 2, there is usually only one value of x corresponding to the value of y.

But, it can be noticed for compressors of Class 3 that there is almost always more than one value of x corresponding to the value of y. If the compressor is always to be run with both cylinders connected, then a value of x can be selected from the part of the curve between $x=1$ and $x=8$.

Sometimes it is desired to disconnect one cylinder of a two-cylinder compressor. In this case, if the flywheel has been calculated in accordance with the curves for Class 3 for a value of x between $x=1$ and $x=8$, there is danger of trouble because the disconnection of one cylinder throws the compressor into Class 1. For this reason, the curves for Class 1 are shown in the range between $x=4$ and $x=7$, so as to make it possible to calculate the current pulsation of a two-cylinder compressor when one cylinder is disconnected.

When one cylinder of the compressor is disconnected, the indicated horse power is cut in half and the value of ρ is usually less than 50 per cent. Reference to Fig. 7, the curve for Class 1, shows that if the flywheel had been calculated for $x=6$, and the value of ρ is less than 50 per cent, it is possible that the current pulsation will not exceed 110 per cent. However, except for very low speed compressors, it is usually better to take a value of x from the branch of the curve beyond $x=10$, if it is desired to operate with only one cylinder of a two-cylinder double-acting compressor.

It should also be noted that for high-speed compressors, approximately 200 r.p.m., it is often impractical to build the synchronous motor with a small enough WR^2 to give a value of x between the limits $x=1$ and $x=8$. In these cases, it is necessary to use the portion of the curve beyond $x=10$.

Cautions

(1) These curves cannot be used for compressors which do not fall into one of the classes described. The suction pressures should lie between 15 and 30 lb. gauge and the discharge pressures between 150 and 250 lb. gauge.

(2) If one cylinder is larger than the other, as in a two-stage compressor, these curves do not apply.

(3) If the compressor will be run at part loads by any method whatsoever, such as changing the clearance, etc., these curves do not apply.

(4) Wherever no hardship is involved, an amount of WR^2 should be used giving the smallest value of current pulsation. Stay away as far as practical from the steep parts of the curves. Changes in frequency of the alternating-current supply, such as a variation in a nominally 60-cycle supply from 58 to 62½ cycles, will change the value of x. At points where the curve is steep, a small change in x might cause a large increase in current pulsation.

Example

Given a two-cylinder, single-acting compressor with cranks at 180 deg., each cylinder 14 in. diameter by 16 in. stroke. The indicated horse power, when operating between maximum pressures, is 155. The length of connecting rod is 35 in. The weight of reciprocating parts is 675 lb.

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(11) This is strictly applicable only for unity power-factor motors. An approximation can be made for 0.8 power-factor motors by multiplying equation (3) by the power-factor. For lower power-factors, the current pulsation is the square root of the sum of the squares of the pulsating power current and an approximately constant reactive current. For the indicated horse power, see footnote (5).

(12) If 66 per cent current pulsation is desired, it is advisable to put in a margin of 6 per cent by aiming the calculations for a 60 per cent pulsation.

This compressor will be driven by a synchronous motor rated as follows:

ATI—50 poles—120 kv-a. 150 h.p.—unity p-f.—150 r.p.m. 2300 volts—3 phase—62½ cycles.

$$P_o = 280 \text{ kw.}$$

$$\beta = 0.3$$

1. $\rho = \dfrac{i.h.p.}{h.p.} = \dfrac{155}{150} = 1.03$

2. $y = \dfrac{60}{\rho} = 58\%$

3. $l = \dfrac{\textit{connecting rod length}}{\textit{crank length}} = \dfrac{35}{8} = 4.38$

4. $Q_2 = \dfrac{6.5\, WS^3 r^2 10^{-8}}{\textit{i.h.p. of compressor}} = \dfrac{6.5 \times 10^{-8} \times 675 (150)^3 (8/12)^2}{155} = 0.426$

5. $\lambda = \dfrac{40\ \beta\ kw.}{P_o \times poles} = \dfrac{40 \times 0.3 \times 120}{280 \times 50} = 0.1$

The compressor belongs to Class 2. Since Q is so small, we are in the range where the value of l is not important. From the curves we find that where $Q_2 = 0.426$, $y = 58$ per cent, $x = 11$ (approximately).

6. Required $WR^2 = \dfrac{P_o f\, 10^{8}_{o}}{0.8\, S^4} \times x =$

$$\frac{280 \times 62\tfrac{1}{2} \times 10^8}{0.8\,(150)^4} \times 11 = 47{,}500 \text{ lb. ft. sq.}$$

Therefore, the motor will either have to be designed with a WR^2 of 47,500 lb. ft. sq., or an extra flywheel will have to be furnished to make up this total, if it is desired to have 66 per cent current pulsation with a factor of safety of 6 per cent.

The Committee on Synchronous Motor Design, in the specification for synchronous motors driving ammonia compressors, has requested a certain amount of information concerning the compressor, such as the ratio of connecting rod length to crank length, weight of reciprocating parts, etc. It will be noticed that this information is required in order to use these curves with accuracy. If the information is not known, two courses are open, as follows:

(1) Assume the smallest values of Q and l which are likely to be met. By doing this, a much larger flywheel will be recommended than is perhaps necessary.

(2) The other course is to assume some intermediate values of Q and l, in which case the flywheel might not be large enough to keep the current pulsation within the guarantee.

If the compressor does not belong to one of the three foregoing standard classes, and if an x-y curve has not already been prepared for the particular class to which the compressor happens to belong, a crank effort diagram or complete data on the compressor are required, as outlined in the specification, in order to construct an x-y curve.

Non-sticking Valves for Caustic Solutions

In the November, 1921, issue of the General Electric Review there appeared on page 949 an article describing the preparation and characteristics of a new bearing metal—Genelite. This material has proved to be entirely free from "freezing" troubles and will not flow or weld to the journal metal even under severe service.

Recently, Genelite has been successfully used in the making of stop-cocks and sliding surface valves for handling caustic solutions. It has been found that the new alloy cannot be corroded by any solution which does not attack bronze.

Genelite is a synthetic bronze, having uniformly distributed throughout its mass approximately 40 per cent by volume of very finely divided graphite. It was developed in the Research Laboratory of the General Electric Company as a bearing material which would actually absorb and hold the lubricant within its pores. The new use for Genelite promises to alleviate much trouble in handling industrial solutions of a corrosive nature.

In Memoriam: Edward R. Stettinius

Edward R. Stettinius, since January, 1919, a member of the Board of Directors of the International General Electric Company and since September, 1921, a member of the Board of Directors of the General Electric Company, died early Thursday morning, September 3rd, at his home on Long Island.

Mr. Stettinius was born in St. Louis, February 15, 1865. He was educated in St. Louis and started work there. He later became interested in the manufacture of steam boilers for power houses, in a company which later was consolidated with the Babcock & Wilcox Company, of which he then became Vice-President and remained a member of the Board of Directors until his death. He later became President of the Diamond Match Company and served in this capacity until he organized on behalf of J. P. Morgan the purchasing of supplies for the Allies in 1915, and spent, in the time before the U. S. entered the war, $3,000,000,000 for munitions. He did this work so admirably that he was invited to become a partner of J. P. Morgan and Company, January, 1916.

EDWARD R. STETTINIUS

As Purchasing Agent for the Allies he had a most complicated problem to deal with, involving the question of labor, building factories and providing adequate facilities and an efficient staff on short notice. When America entered the war President Wilson invited Mr. Stettinius to become Surveyor General of War Supplies for the War Department, and later Second Assistant Secretary of War.

In July, 1918, he went to France as a member of the Munitions Council, which centralized the control of all Allied economic forces.

His services have been signally recognized by foreign Governments as well as our own.

After the war he returned to this country and in January, 1919, when the International General Electric Company was organized I asked Mr. Stettinius to serve as a member of the Board of Directors. He did not desire to do this, as he had so many other duties, but on account of his association with the development of large industries, both in this country and abroad, and also because of his interest and intimate knowledge of economic conditions outside of this country, I knew he could be of great assistance in the formation and organization of the International General Electric Company, and I urged him to go on the board. It was an evidence of his generous spirit that he said "All right, I will come on the board and help you." In this way Mr. Stettinius became acquainted with Mr. Coffin, and others sitting on the Board of Directors of the International General Electric Company, who learned to appreciate the value of his vision and counsel. In the fall of 1921 Mr. Coffin asked Mr. Stettinius to go on the board of the General Electric Company.

To both of these companies he has always given his services when called upon, and his untiring zeal and clear vision were of the greatest assistance both to the International General Electric Company and the General Electric Company. He was tireless in his efforts to be of service, and indeed his early and untimely death is a result of his generous giving of himself for the cause of the country in the war and the cause of the industries and his associates in peace. His kindliness, his rugged honesty and sterling qualities endeared him to his associates, and he will be sorely missed by all those who were privileged to know him.

GERARD SWOPE, *President,*
General Electric Company.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Arc Welding

Arc Welding in Ship Building. Strelow, W.
Weld. Engr., July, 1925; v. 10, pp. 19-21.

Brakes

Brakes for Slowing Down Electrical Generators. Lewinnek, G.
AEG Progress, June, 1925; pp. 87-90.
(Describes A. E. G. equipment for reducing the time required for bringing water-driven generators to rest when shutting them down.)

Circuit Breakers

Oil Circuit Breaker Situation from an Operator's Viewpoint. Stone, E. C.
A.I.E.E. Jour., July, 1925; v. 44, pp. 756-761.
(Not an original study, but an assembly of existing information intended to stimulate discussion. Special attention to interrupting duty.)

Electric Control Systems

Supervisory System Supplements Automatic Substation Control. Butcher, C. A.
Elec. Rwy. Jour., July 11, 1925; v. 66, pp. 53-56.
(Illustrated account of equipment used by the Staten Island Rapid Transit Railway.)

Electric Drive—Ice Manufacture

Electrically Driven Ice Plant. Ophuls, Fred.
Refrig. Engng., June, 1925; v. 11, pp. 419-428.
(Revision of the discussion of this paper as originally presented in the May issue.)

Electric Drive—Textile Mills

Electric Drive in Carpet Mills.
Elec. Rev., July 3, 1925; v. 97, pp. 20-22.
(Illustrated description of an installation in an English carpet factory.)

Electric Furnaces

Replacing Oil with Electricity. Walsh, W. J.
Iron Age, July 16, 1925; v. 116, pp. 145-146.
(Brief account of methods used and economies effected by changing an oil-fired heat-treating furnace to electric heating.)

Electric Locomotives

A. R. A. Reports on Electric Rolling Stock.
Rwy. Elec. Engr., July, 1925; v. 16, pp. 215-219.
("Future possibilities of steam and electric locomotives—Shop facilities required for electric power.")

Electric Locomotives

High Speed Electric Locomotives. Weiss, M.
Int. Rwy. Cong. Assoc. Bul., June, 1925; v. 7, pp. 2111-2114.
(A short summary and findings on Reports Nos. 1 and 2 presented at the tenth session of the International Railway Congress Assoc., and printed in the Jan. and April issues, respectively.)

Electric Transformers

Voltage Control Obtained by Varying Transformer Ratio. Blume, L. F.
A.I.E.E. Jour., July, 1925; v. 44, pp. 752-755.

Electric Transformers—Testing

Separate Leakage Reactance of Transformer Windings. Dahl, O. G. C.
A.I.E.E. Jour., July, 1925; v. 44, pp. 735-741.
(Discusses a method for determining such leakage reactance.)

Electric Transmission Lines

Voltage Regulation of Three-phase Transmission Lines. Cotton, H.
Wld. Power, July, 1925; v. 4, pp. 3-10.
(Theoretical.)

Electrical Machinery—Temperature

Design, Construction and Operation of Air-Coolers for Turbo-Generators. Pohl, R.
AEG Progress, June, 1925; pp. 102-108.
(Illustrated discussion of cooling principles and of A. E. G. coolers already built.)

Hydrogen as a Cooling Medium for Electrical Machinery. Knowlton, Edgar, and others.
A.I.E.E. Jour., July, 1925; v. 44, pp. 724-734.
(Presents results of theoretical study and tests.)

Electricity—Applications—Domestic

Household Refrigeration and Research Work. Spreen, C. C.
Refrig. Engng., June, 1925; v. 11, pp. 416-417, 432.

Electricity—Theory

Law, Description and Hypothesis in the Electrical Science. Pupin, M. I.
A.I.E.E. Jour., July, 1925; v. 44, pp. 741-746.
(The first Steinmetz lecture.)

Electroplating

Electrodeposition of Rubber. Sheppard, S. E., and Eberlin, L. W.
Ind. & Engng. Chem., July, 1925; v. 17, pp. 711-714.
(Shows that rubber compounds may be electrolytically deposited upon metals and other materials.)

Furnaces, Industrial

Determination of Furnace Efficiencies and Heat Treating Costs. Ipsen, C. L.
Am. Soc. St. Treat. Trans., July, 1925; v. 8, pp. 36-47.

Fuels and Furnaces for Heat Treating. Trinks, W.
Am. Soc. St. Treat. Trans., July, 1925; v. 8, pp. 58-83.

Gearing

Gearing as a Medium of Industrial Power Transmission. Stone, O. N.
Am. Soc. St. Treat. Trans., July, 1925; v. 8, pp. 48-57.

Heat Insulation

Insulation of Hot Surfaces and Furnace Walls. McMillan, L. B.
Iron & St. Engr., July, 1925; v. 2, pp. 301-310.
(Includes numerous charts and curves pertaining to heat loss.)

Insulation—Testing

New Method and Means for Measuring Dielectric Absorption. Marbury, Ralph E.
A.I.E.E. Jour., July, 1925; v. 44, pp. 718-723.
(Describes the "dielectric lag meter" and presents test data secured by its use. Includes list of 20 references.)

Load Dispatching

Power Economies Through Load Dispatching. Richardson, Henry A.
Ind. Man., July, 1925; v. 70, pp. 1-4.

Power-factor

Synchronous Motors Used for Voltage and Power-Factor Regulation. Mortensen, S. H.
Power, July 14, 1925; v. 62, pp. 47-49.

Power Plants, Electric

Trenton Channel Plant of the Detroit Edison Company. Hirshfield, C. F.
A.I.E.E. Jour., July, 1925; v. 44, pp. 708-718.

Railroads—Electrification

Electrification of Staten Island Lines.
Rwy. Elec. Engr., July, 1925; v. 16, pp. 201-207.

Speed Regulation

Speed Control in Interborough Subway.
Elec. Rwy. Jour., July 11, 1925; v. 66, pp. 49-52.

Steam Turbines, Marine

Reblading and Balancing Turbines on Shipboard. McDowell, C. S.
Pacific Mar. Rev., July, 1925; v. 22, pp. 321-323.

Street Lighting

Chicago Residence Street Lighting. Hail, J. C.
W. Soc. Engrs. Jour., July, 1925; v. 30, pp. 286-295.

Need for Adequate Street Lighting. Haas, O. F.
W. Soc. Engrs. Jour., July, 1925; v. 30, pp. 283-286.

Voltage Regulation

Charts for Regulation of Transformers. Boelsterli, Arthur A.
I.E.E. Jour., July, 1925; v. 63, pp. 692-696.

Water Flow

New Formula for Flow of Water in Clean Cast-Iron Pipe. Wegmann, Edward, and Aeryns, Albert N.
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Water Turbines

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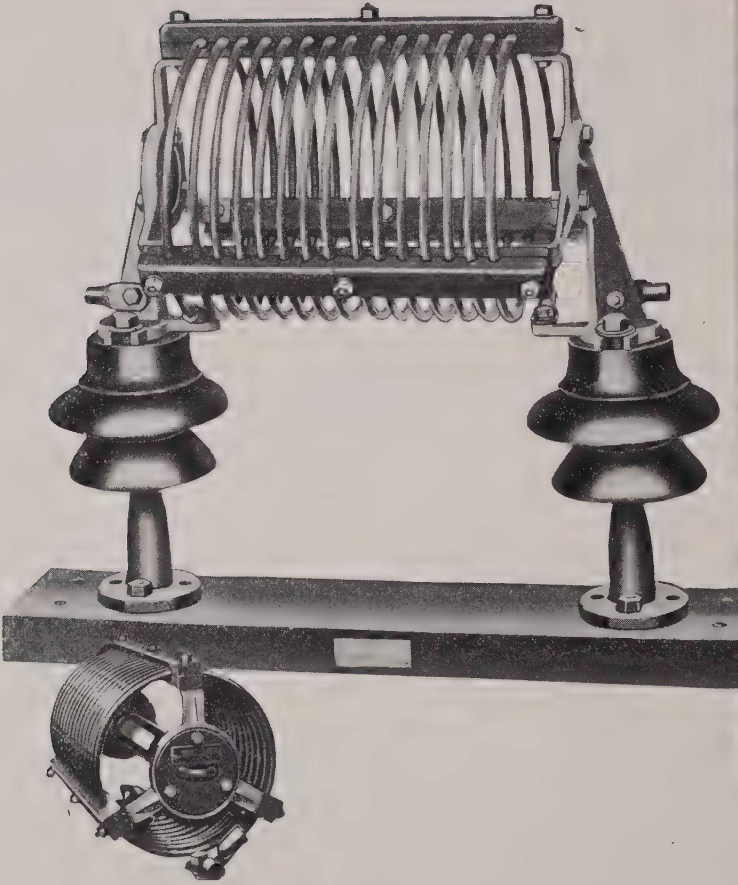

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20-18

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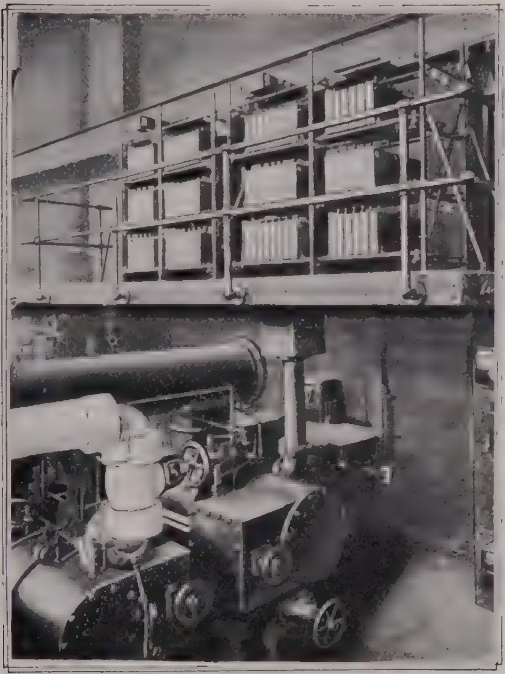

The 350 kv-a. Capacitor installation that effected this saving

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Improved power factor saved for a Long Island chemical plant the cost of an additional boiler, generator and auxiliaries.

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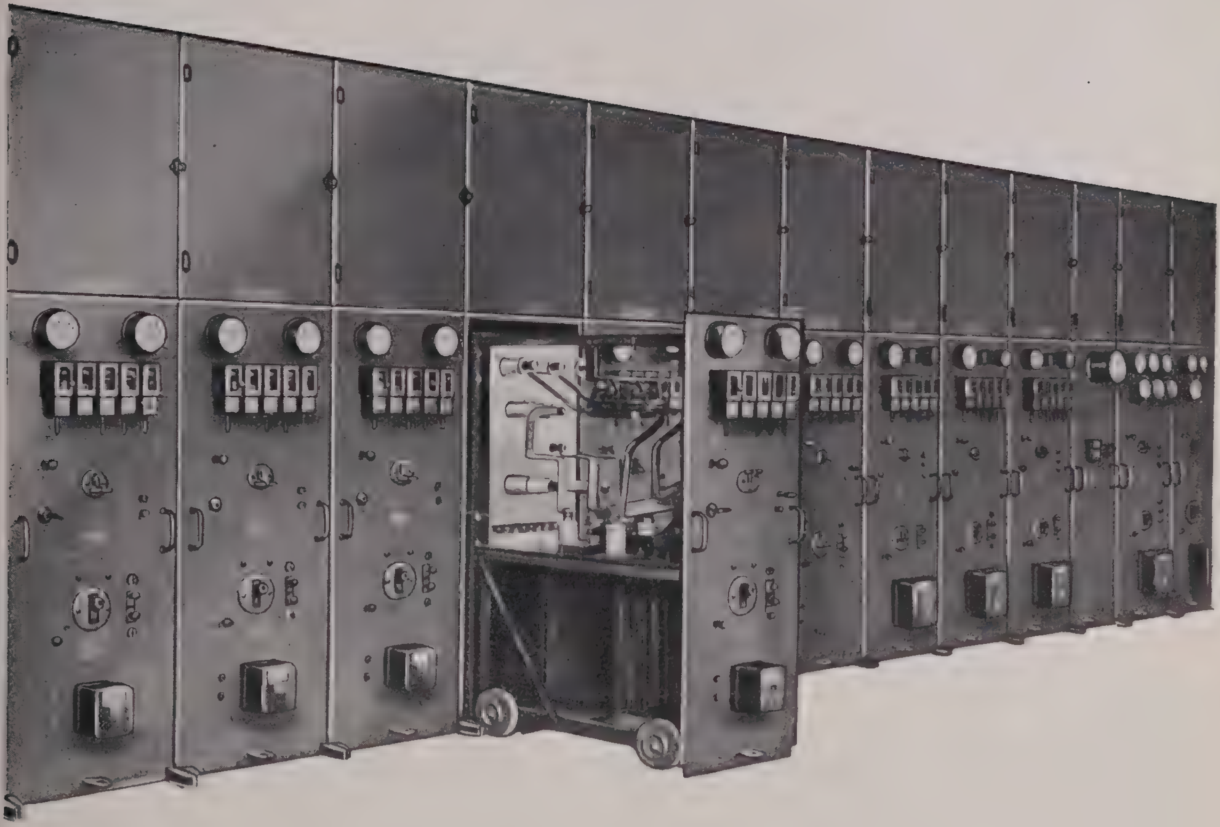

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22B-3 B

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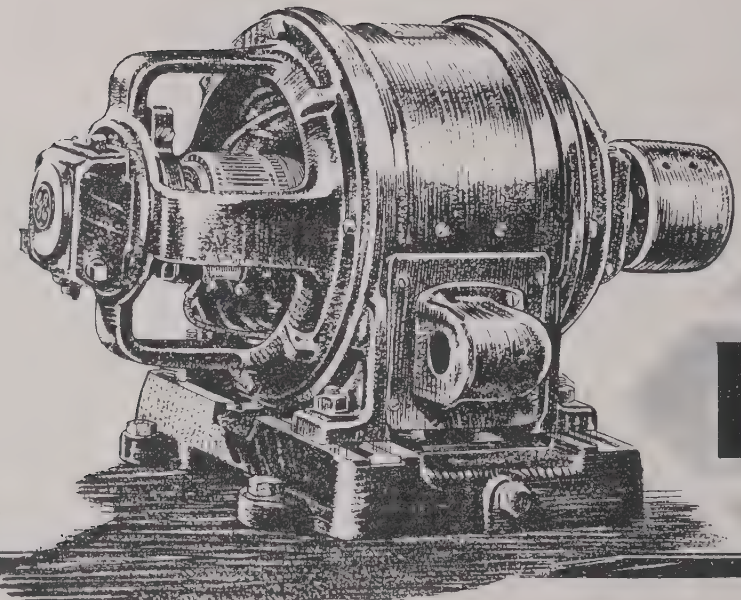

Sizes
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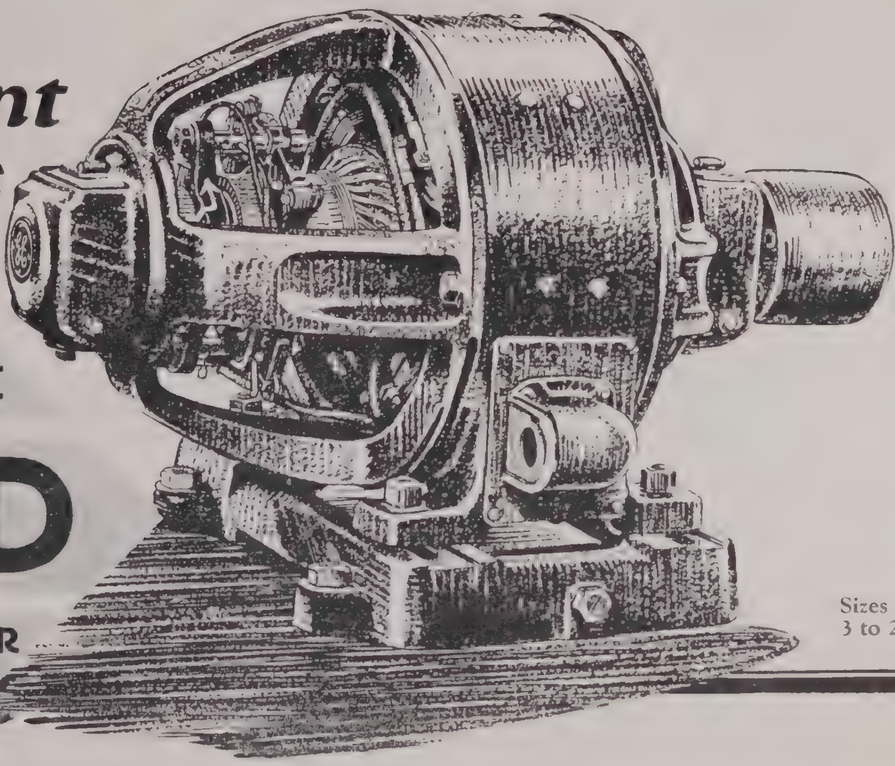

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8A 3B

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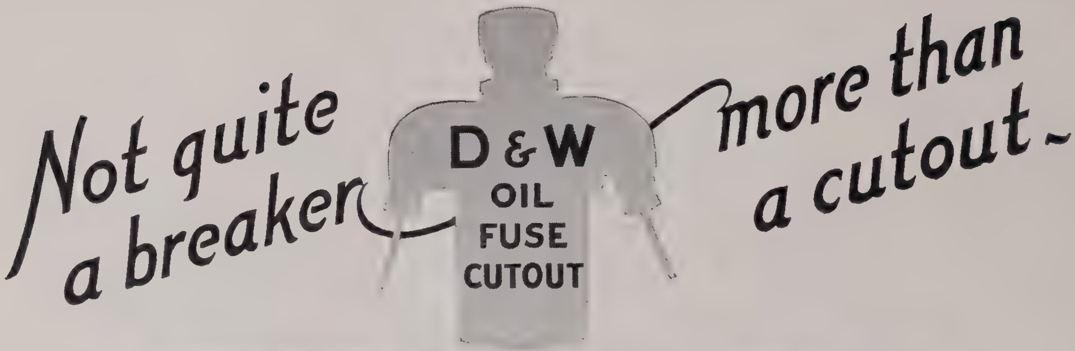

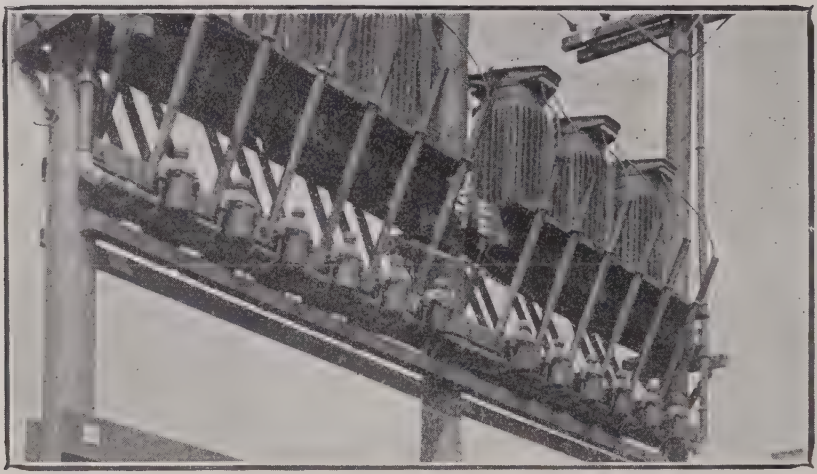

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Doubtless you have heard some cutout fuses blow with a deafening noise and an alarming sheet of flame like a rocket.

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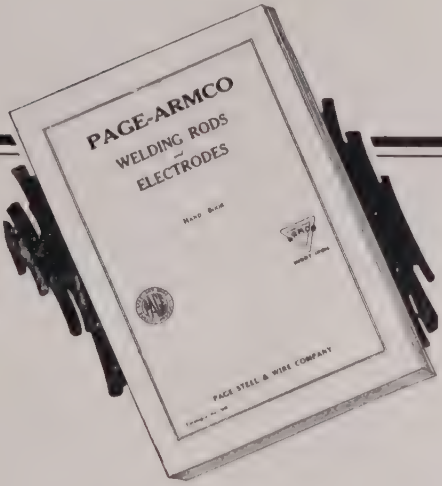

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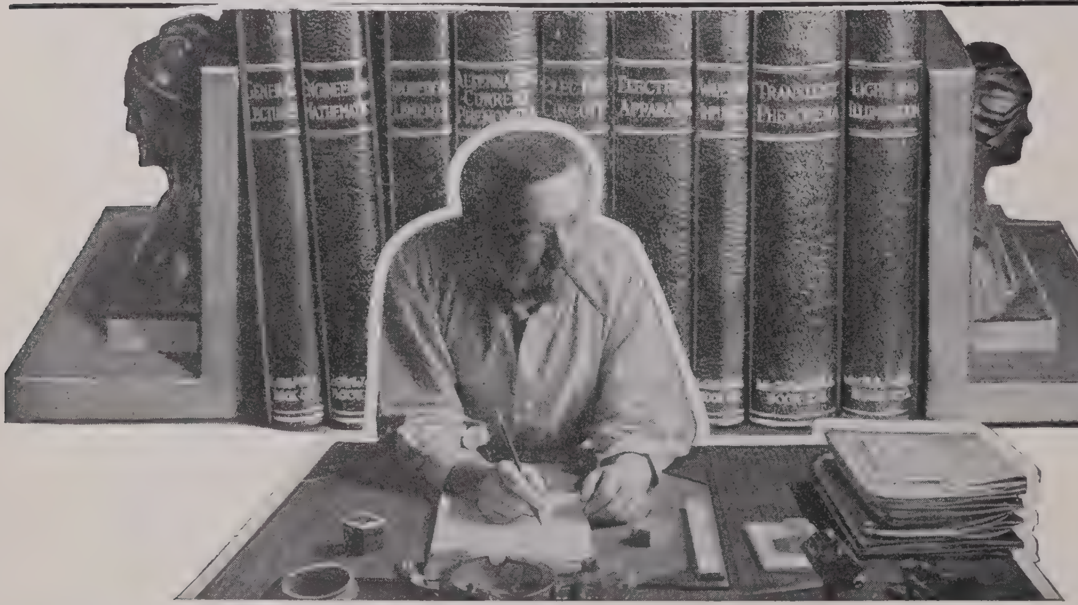

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G.E.-10-1-25

The General Electric Review for December, 1907

was a 48-page number. It presented eight short articles, six of which were illustrated with half-tone cuts. Among the contributors were Dr. Steinmetz, T. C. Martin and John R. Hewett.

The advertising matter was all on the cover and comprised three General Electric advertisements featuring respectively the Tirrill voltage regulator, motor-starting equipments, and switchboards.

This issue, number one of volume ten, presents a quaint appearance today, but is an excellent specimen of the printing of its time. It was produced, as all successive numbers have been, by

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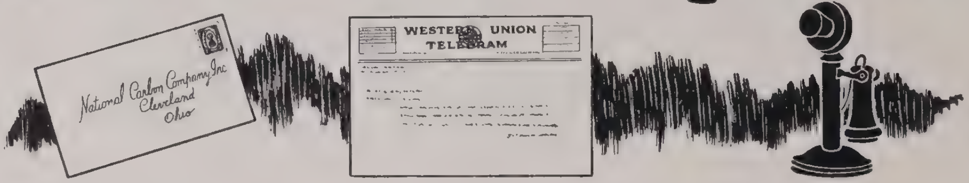

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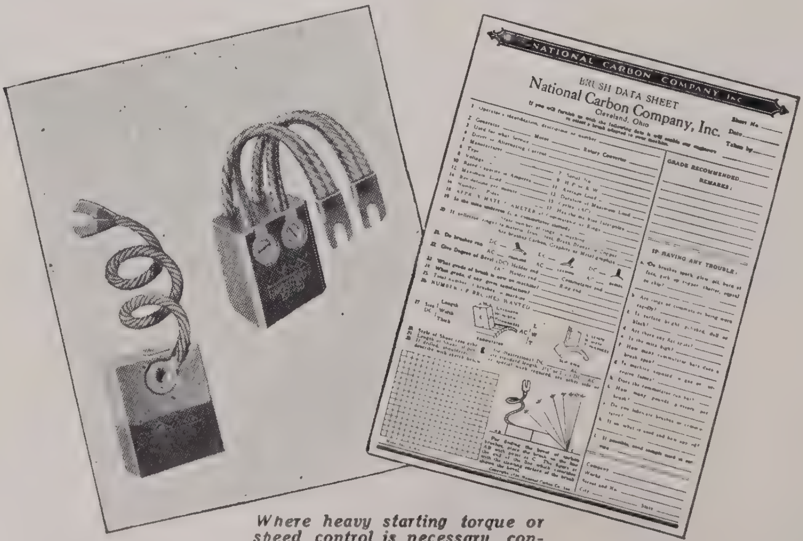

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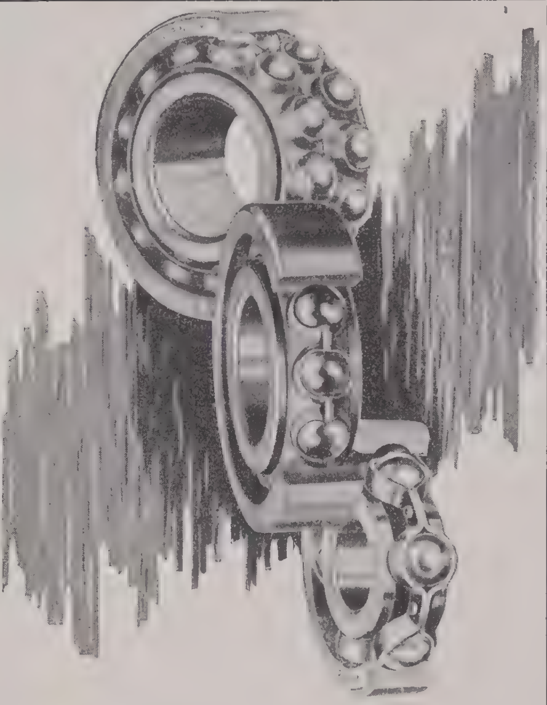
General Electric Review

The Index of Electrical Development



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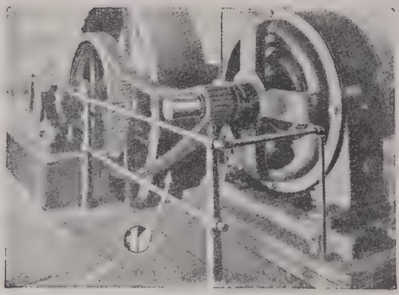

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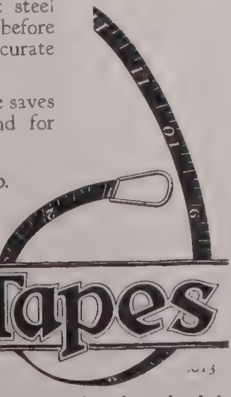

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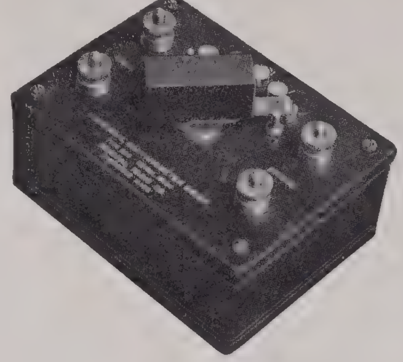

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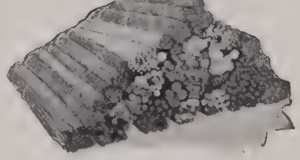

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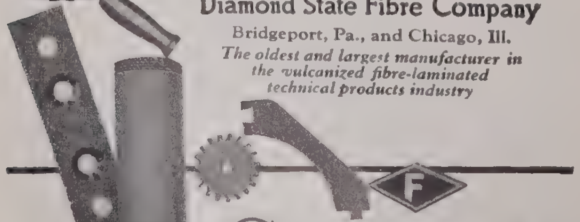

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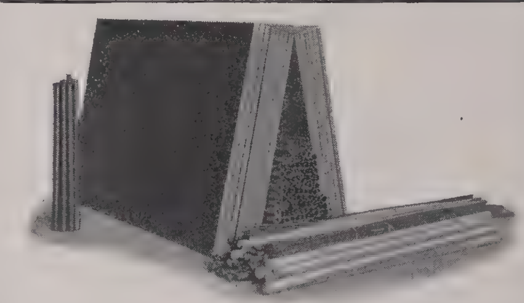

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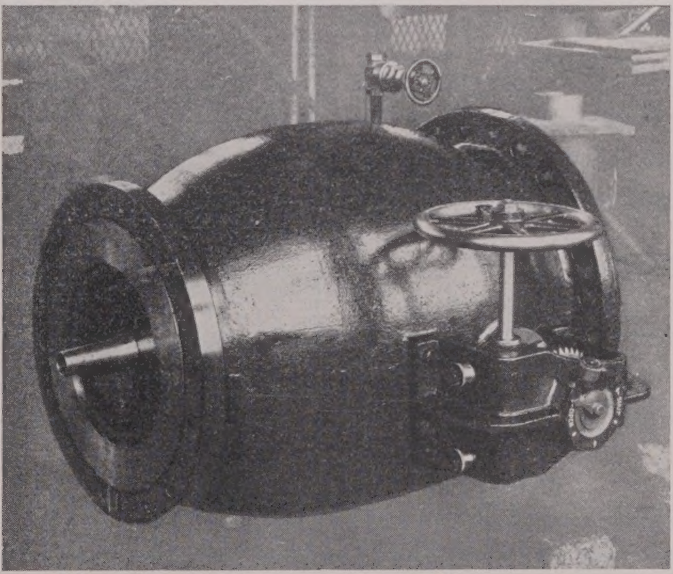

18-inch Johnson Valve built for the Southern Sierras Power Company and designed for free discharge into the atmosphere under a head of 400 feet

Special Johnson Valve Features

Simplicity of Operation
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ELECTRIC in all sizes **STEAM up to 1000 H.P.**

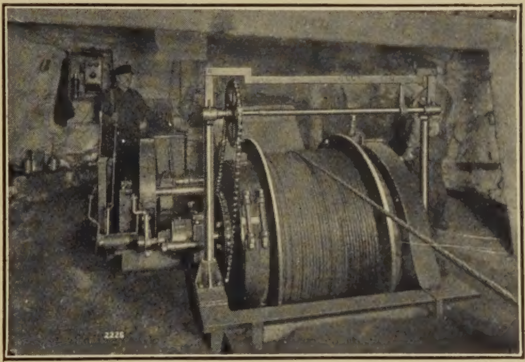

Illustration shows a slope hoist, operating an underground incline 1700 feet long. It has been in use by The Spencer Coal Co. for a number of years, and has given excellent satisfaction, both in service performed, and its wearing quality.

WE BUILD mine hoists, both steam and electric, in types to meet every kind of mine service.

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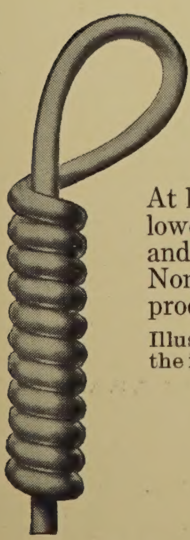
Double Galvanized Telephone and Telegraph Wire



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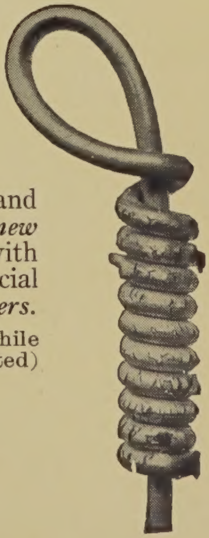
Non-Peeling—Non-Cracking

At last the Telephone and Electrical Industry is assured longer life and lower maintenance on galvanized wire construction through our *new* and *improved* patented Galvanizing Process, which insures a wire with Non-Peeling and Non-Cracking Zinc Coating. Now in full commercial production. Carried in stock by Representative *Supply Jobbers.*

Illustration at right shows what happens to old process galvanizing, while the illustration at left shows assured results of CRAPO PROCESS—(patented)

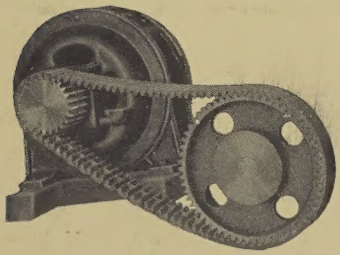
Galvanized Steel Strand

Standard or Commercial, Siemens-Martin, High Strength and Extra High Strength Grades



Indiana Steel & Wire Company, - - Muncie, Indiana

"Silent Chain Drives Would Have Prevented This Loss"



Drives Now Carried in Stock

Link-Belt Silent Chain Drives, from ½ to 10 H. P., in almost any speed ratio from 1 to 1 up to 7 to 1, can now be obtained from stock from a Link-Belt Distributor near you. Send for Book 725, or name of your nearest distributor.

ANOTHER drive breakdown, the third in two days.

And breakdowns of drives are breakdowns of production.

Of course it had to come just when the plant was overloaded—just when every single minute counts.

No wonder the owner is worried by the telltale figures on his plant's Production Sheet. He doesn't see any sense in it.

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There's only one way to avoid the loss.

Employ Link-Belt Silent Chain Drives for *continual trouble-free* production. Power delivered in a straight line; floor space saved; efficiency certain; such long life that they quickly "pay out".

Link-Belt Silent Chain Drives speed production—never slow it up. Savers of time, temper and money,—eliminators of waste. All the facts are given in price-list Data Book No. 125.

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